POCKET BOOK OF AERONAUTICS

MOEDEBECK - VARLEY

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BY

HERMANN W. L. MOEDEBECK

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TRANSLATED BY

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TRANSLATOR'S PREFACE

THE widespread interest in aeronautical matters at the present time has been mainly aroused by the success which has at length rewarded the efforts of inventors in designing air-ships and flying-machines. These, although very far from perfect, can at least be maintained aloft for long periods and be steered in any desired direction, representing a great advance on anything achieved at the beginning of the last decade.

No small handbook recording the history and development of aerial navigation, and presenting a summary of the state of the science at the present day, has hitherto been available for English readers: when, therefore, Mr Alexander, the well-known authority on aeronautics, suggested to the writer that he should undertake the translation of Major Moedebeck's *Pocket-Book for Aeronauts*, he was glad to have the opportunity of bringing before the English-speaking public this comprehensive *résumé* of the whole subject of Aeronautics.

Major Moedebeck and his collaborators treat the subject throughout from both theoretical and practical standpoints, and have, furthermore, incorporated chapters of great scientific interest on such subjects as the physics of the atmosphere, and also sections giving historical summaries of the advances of the separate branches of aeronautics from the earliest times up to the present day.

It is now nearly three years since the second German edition of the pocket-book was published. Major Moedebeck and his

collaborators, especially Mr Chanute, have, however, kindly furnished the translator with much new material in order that this edition may be thoroughly up to date, and practically correspond to a later and revised edition of the German work. The translator himself has revised and greatly amplified the Appendix, adapting various original Tables for the use of English readers, and adding several new Tables for the conversion of metric units into English units. An Index has also been added.

In conclusion, the translator must acknowledge the kind assistance in revising various sections of the manuscript or proofs of Lieutenant Westland, of the Royal Engineers (in connection with the sections relating to Military Ballooning), Mr W. C. Houston, B.Sc. (in connection with Chapter XIV., to which he contributed a new section on Internal Combustion Engines), Messrs F. Unwin, M.Sc., and W. H. F. Murdoch, B.Sc., A.M.I.E.E.; above all he must, however, express his deep gratitude to Mr J. Stephenson, B.Sc., A.R.C.S., of Cardiff University College, for his thorough and painstaking revision of the whole of the proofs, and for innumerable valuable suggestions.

W. M. V.

EDINBURGH, *January* 1907.

AUTHOR'S PREFACE TO THE ENGLISH EDITION

Die englische Ausgabe meines Taschenbuchs für Flugtechniker und Luftschiffer ist in erster Linie den beiden bekannten Flugtechnikern Mr Patrick Y. Alexander, in Southsea (England), und dem Ingenieur O. Chanute, in Chicago (U.S.A.), zu verdanken.

Das Buch stellt eine Systematik der aëronautischen Wissenschaften vor, die grade jetzt bei dem Aufschwunge dieser Technik jedem Interessenten als Basis für weiteres Schaffen von Nutzen sein wird. Die darin enthaltene Vielseitigkeit der technischen Materie hat die Übersetzung ins Englische zu einer sehr zeitraubenden, schweirigen Arbeit gemacht, der Dr Mansergh Varley mit grossem Eifer abgelegen hat, was die Interessenten englischer Zunge ihm besonders werden zu danken haben.

Mir und meinen werthen Mitarbeitern wird es eine besondere Genugthuung bieten in dem weit über die ganze Welt verbreiteten englischen Sprachgebiet in bescheidenem Masse zur Förderung der Aeronautik angeregt und mitgewirkt zu haben.

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Major und Bataillons Kommandeur
im Badischen Fussartillerie Regiment Nr. 14.

Strassburg i. E., Silbermannstrasse 14,
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ABBREVIATIONS

D. R. P. = *Deutsches Reichs-Patent.*
H.P. = Horse-power.
I. A. M. = *Illustrierte Aëronautische Mitteilungen.*
L'Aé. = *L'Aéronaute.*
R. de l'Aé. = *Revue de l'Aéronautique.*
Z. f. L. = *Zeitschrift für Luftschiffahrt.*

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POCKET BOOK OF AERONAUTICS

CHAPTER I.

ON GASES.

A.—THE PHYSICAL PROPERTIES OF GASES.

By Dr R. EMDEN,
Of the Kgl. Techn. Hochschule, Munich.

§ 1. SYSTEM OF MEASUREMENT AND NOTATION.

Throughout this chapter, lengths, weights, and times will be given in metres, kilograms, and seconds respectively; areas in square metres, and volumes in cubic metres.

We will denote by—

p = the pressure measured in kilograms weight per square metre.

p_0 = normal atmospheric pressure = $10333 \dfrac{\text{kilograms}}{\text{square metre}}$
= pressure of a column of mercury 0·76 metres high at sea level in latitude 45°.

b = pressure in millimetres of mercury.

t = temperature on the centigrade scale, $t_0 = 0°$ C.

T = absolute temperature = $273 + t$.

$\alpha = \frac{1}{273} = 0 \cdot 003665$.

ρ = density, *i.e.* the number of kilograms per cubic metre at a pressure p and temperature t.

ρ_0 = normal density, *i.e.* the density when $p = p_0$ and $t = t_0$.

v = specific volume, *i.e.* the volume of a kilogram at a pressure p and temperature t.

v_0 = specific volume for $p = p_0$ and $t = t_0$. Obviously $v\rho = 1$

s = specific gravity of a gas, *i.e.* the weight of unit volume of the gas as compared to the weight of unit volume of air measured under the same p and t, often also called the density of the gas as compared to air = 1.

§ 2. CHARACTERISTIC EQUATIONS OF A GAS.

The two following equations connecting p, v, ρ, and t hold with great exactness for all gases:—

$$(1a) \quad \frac{p}{\rho(273+t)} = \frac{p_0}{\rho_0 273} = \mathrm{R};$$

$$(1b) \quad \frac{pv}{273+t} = \frac{p_0 v_0}{273} = \mathrm{R};$$

according as we deal with (a) unit volume, or (b) unit weight of the gas.

R is called the gas constant.

$$\mathrm{R}\ (\text{for air}) = \frac{10333}{1{\cdot}293 \times 273} = 29{\cdot}27.$$

The constant varies for different gases inversely as the density of the gas (see Table VIII.). An important consequence of this is that

$$s = \frac{\rho(\text{gas})}{\rho(\text{air})} = \frac{\mathrm{R(air)}}{\mathrm{R(gas)}} = \text{a constant.}$$

i.e. *the specific gravity of a gas is independent of the pressure or temperature.*

§ 3. DEDUCTIONS FROM THE CHARACTERISTIC EQUATIONS.

We can alter the conditions of a gas in several different ways.

A. The temperature is kept constant. The characteristic equation gives

$$\rho_1 : \rho_2 = p_1 : p_2$$
$$v_1 : v_2 = p_2 : p_1$$

When the temperature of a gas is kept constant, the density is proportional to the pressure, the volume inversely proportional to the pressure. (Boyle or Mariotte's Law.)

B. The pressure is kept constant.

$$v_1 : v_2 = 273 + t_1 : 273 + t_2 = 1 + at_1 : 1 + at_2 = \mathrm{T}_1 : \mathrm{T}_2$$
$$\rho_1 : \rho_2 = 273 + t_2 : 273 + t_1 = 1 + at_2 : 1 + at_1 = \mathrm{T}_2 : \mathrm{T}_1.$$

When the pressure of a gas is kept constant, the volume is proportional to the absolute temperature, the density inversely proportional to the absolute temperature.

Further, it follows that

$$v = v_0(1 + \tfrac{1}{273}t) = v_0(1 + \alpha t).$$

When the pressure of a gas is kept constant, its volume increases $\frac{1}{273}$ *(or nearly* 0·4 *per cent.) of its value at* 0° *C. for every rise in temperature of* 1° *C.* (Charles' Law.)

C. The volume (and therefore ρ) is kept constant.

$$p_1 : p_2 = 273 + t_1 : 273 + t_2 = 1 + \alpha t_1 : 1 + \alpha t_2 = T_1 : T_2.$$

When the volume of a gas is kept constant, the pressure is proportional to the absolute temperature.

Further, it follows that

$$p = p_0(1 + \tfrac{1}{273}t) = p_0(1 + \alpha t).$$

When the volume of a gas is kept constant, the pressure increases $\frac{1}{273}$ *(or nearly* 0·4 *per cent.) of its value at* 0° *C. for every rise in temperature of* 1° *C.*

§ 4. HEIGHT OF THE HOMOGENEOUS ATMOSPHERE.

The introduction of a gas constant $H_0 = 273$ R gives the characteristic equations of a gas in a form more convenient for many purposes.

$$(2a) \quad \frac{p}{\rho} = H_0(1 + \alpha t) = H \text{ (metres)}$$

$$(2b) \quad pv = H_0(1 + \alpha t) = H \text{ (metres)}.$$

H is termed the height of the homogeneous atmosphere. It is the height of a column of air of constant density ρ which exerts the pressure p at its base. (For values of H_0 see Table VII.)

§ 5. CALCULATION OF THE DENSITY OF A GAS.

Given t, and the pressure p in $\dfrac{\text{kilograms}}{\text{square metre}}$, the density is given by (2*a*) as

$$(3) \quad \rho = \frac{p}{H_0(1 + \alpha t)} \left(\frac{\text{kilograms}}{\text{cubic metre}}\right).$$

If the pressure is given as b mm. of mercury, we can write equation (1*a*) in the form

$$\frac{b}{\rho(273 + t)} = \frac{760}{\rho_0 273};$$

or if we write

$$a = \frac{\rho_0}{760}\left(\frac{\text{kilograms}}{\text{cubic metre} \times \text{mm. Hg}}\right),$$

then

$$(4) \quad \rho = ab \frac{1}{1+\alpha t}\left(\frac{\text{kilograms}}{\text{cubic metre}}\right).$$

(For values of a, see Table VII.)

If the density at a given height is required, b may be calculated from the barometric height formula, or taken from Table XIII., and substituted in equation 4, or the factor n, corresponding to the given height, may be taken from Table XV., and the density calculated from the formula

$$(5) \quad \rho = \frac{\rho_0}{n} \quad \frac{1}{1+\alpha t}.$$

§ 6. MIXTURES OF GASES.

Dalton's Law.—*In a mixture of gases, each gas obeys its own characteristic equation independently of the presence of the remaining gases.*

Deductions.—The mixture of gases possesses a characteristic equation of its own, just as in the case of a simple gas (example: air). The pressure of the mixture is equal to the sum of the pressures exerted by its constituents, and the gas constant of the mixture can be calculated from those of its constituents, knowing the proportion of each gas present. (In the practical application of Dalton's Law, the only case which needs consideration is that in which all the gases are at the same temperature before the mixing, and in which no change of temperature occurs in the mixing.)

The exact import of the law will be better understood by the following examples:—

(a) Volumes $V_1, V_2, \ldots V_n$ cubic metres of permanent gases at pressures $p_1, p_2, \ldots p_n$ respectively were mixed in a space of volume V cubic metres. What is the resultant pressure P of the mixture? Since the final pressure of the nth gas $p'_n = p_n \frac{V_n}{V}$, it follows that

$$P = \frac{p_1 V_1 + p_2 V_2 + \ldots + p_n V_n}{V}.$$

(b) If in (a) the densities of the gases before the mixing were $\rho_1, \rho_2, \ldots \rho_n$, what is the density ρ of the mixture?

Since $V_n \rho_n$ kilograms of the nth gas are present in the mixture

$$\rho = \frac{V_1 \rho_1 + V_2 \rho_2 + \ldots + V_n \rho_n}{V}$$

(from which, for example, the density of a mixture of coal gas and hydrogen could be calculated).

(*c*) What is the value of the gas constant R for the above mixture? From (*a*) and (*b*) we get

$$\frac{P}{\rho}=\frac{p_1V_1+p_2V_2+\ .\ .\ .\ +p_nV_n}{\rho_1V_1+\rho_2V_2+\ .\ .\ .\ \rho_nV_n}.$$

Since $\rho_n V_n = M_n$, the weight of the nth gas present, the weight of the mixture $M=\rho_1V_1+\rho_2V_2+\ .\ .\ .\ +\rho_nV_n$. And since the characteristic equation of the nth gas can be written

$$\frac{p_n}{\rho_n}=\frac{p_nV_n}{M_n}=R_nT,$$

it follows that

$$\frac{P}{\rho}=\frac{M_1R_1+M_2R_2+\ .\ .\ .\ +M_nR_n}{M}T=RT$$

or

$$R=\frac{M_1R_1+M_2R_2+\ .\ .\ .\ +M_nR_n}{M}.$$

(*d*) How many cubic metres of oxygen (V_0) and nitrogen (V_N) are contained in 1 cubic metre of air?

Since the proportion of the gases in the mixture is independent of p and t, we will put $p=p_0$ and $t=0°$ C., when we obtain the equations

$$1{\cdot}293\text{ (weight of 1 cubic metre air)}=V_0\rho_0+V_N\rho_N$$
$$1=V_0+V_N,$$

whence

$$V_N=\frac{\rho_0-1{\cdot}293}{\rho_0-\rho_N}=\frac{1{\cdot}429-1{\cdot}293}{1{\cdot}429-1{\cdot}256}=0{\cdot}786$$

$$V_0=\frac{1{\cdot}293-\rho_N}{\rho_0-\rho_N}=\frac{1{\cdot}293-1{\cdot}256}{1{\cdot}429-1{\cdot}256}=0{\cdot}214.$$

Air contains, therefore, 78·6 per cent. of its volume of nitrogen and 21·4 per cent. of its volume of oxygen.

(*e*) How many kilograms of oxygen (M_0) and nitrogen (M_N) are contained in 1 cubic metre of air?

$$1=\frac{M_0}{\rho_0}+\frac{M_N}{\rho_N}$$
$$1{\cdot}293=M_0+M_N,$$

whence (compare (*d*)) $M_N=0{\cdot}987$ kilogram, $M_0=0{\cdot}306$ kilogram.

Air consists, therefore, of 76·4 per cent. nitrogen and 23·6 per cent. oxygen by weight.

(*f*) A cubic metre of a mixture of gases at temperature $t°$ consists of n gases, whose normal densities are $(\rho_0)_1$, $(\rho_0)_2$, . . . $(\rho_0)_n$. The partial pressures of the gases in the mixture are ascertained

to be $p_1, p_2, \ldots p_n$. How many kilograms $\rho_1, \rho_2, \ldots \rho_n$ of each gas are contained in the mixture?

Since the characteristic equation holds for each gas, we have for the nth gas

$$\frac{p_n}{\rho_n(1+at)} = \frac{p_0}{\rho_0}, \text{ and therefore}$$

$$\rho_n = \rho_0 \frac{p_n}{p_0} \cdot \frac{1}{1+at}.$$

Dalton's Law is also applicable in dealing with atmospheric air as a mixture of dry air and aqueous vapour.

§ 7. DENSITY AND PRESSURE OF AQUEOUS VAPOUR.

At all temperatures which come into consideration in meteorological problems aqueous vapour is present in the air in such relatively small proportions that we can treat it, *up to the point of saturation*, as a perfect gas following its own characteristic equation. The specific gravity of aqueous vapour is $0{\cdot}622 = \frac{5}{8}$. In the characteristic equation, therefore, the normal density ρ_0 must be taken as $0{\cdot}622 \times 1{\cdot}293 = 0{\cdot}804$. We measure the pressure e of the unsaturated vapour in mm. mercury, and the total quantity of vapour in a cubic meter f, in kilograms. In a state of saturation we will call these quantities E and F (for values see Table VIII.). For aqueous vapour the constant a of equation $(4) = \frac{0{\cdot}804}{760} = 0{\cdot}00106$, and the relation between e and f is given by the equations:

$$(6) \qquad \begin{cases} f = 0{\cdot}00106 \dfrac{e}{1+at} \left(\dfrac{\text{kilograms}}{\text{cubic metre}}\right) \\ e = 994 f(1+at) \text{ (mm.)}. \end{cases}$$

Since these equations can be applied up to the point at which saturation occurs, we obtain with corresponding accuracy

$$(7) \qquad \frac{e}{E} = \frac{f}{F} \text{ and } \frac{e}{f} = \frac{E}{F}.$$

§ 8. HYGROMETRIC STATE OF THE ATMOSPHERE.

A measure of the quantity of aqueous vapour in the air (or the humidity) can be given in five different ways.

A. **Absolute humidity.**—The actual quantity of aqueous vapour f contained in a cubic metre of air.

B. **Pressure of aqueous vapour.**—The partial pressure e of the aqueous vapour.

The relation between the absolute humidity and the pressure of the aqueous vapour is given by equation (6).

C. **Relative humidity.**—The ratio of f, the actual quantity of aqueous vapour contained in a cubic metre of air, to F, the maximum quantity which it could hold at the same temperature, expressed as a percentage; or, taking into consideration equation (7),

$$\text{(8)} \qquad \text{Relative humidity} = 100\frac{f}{\mathrm{F}} = 100\frac{e}{\mathrm{E}}.$$

D. **The mixture ratio** (μ).—The ratio of the weight of aqueous vapour (f) contained in a cubic metre, to the weight of dry air (ρ). If the moist air has a pressure of b mm. at temperature $t°$, and the aqueous vapour a pressure of e mm., then the partial pressure of the dry air is $b-e$ mm., and (*cf.* § 6*f*)

$$\rho = \rho_0 \frac{b-e}{760}\frac{1}{1+at}$$

$$f = f_0 \frac{e}{760}\frac{1}{1+at};$$

whence

$$\mu = \frac{f}{\rho} = \tfrac{5}{8}\frac{e}{b-e}$$

represents the weight of aqueous vapour mixed with 1 kilo. of dry air.

E. **Specific humidity** (σ).—The weight of aqueous vapour contained in 1 kilogram of moist air. Since from the definition

$$\sigma = \frac{f}{\rho+f} = \frac{\mu}{1+\mu}$$

it follows that

$$\text{(10)} \qquad \text{Specific humidity } \sigma = \tfrac{5}{8}\frac{e}{b-\tfrac{3}{8}e}.$$

§ 9. DENSITY OF MOIST AIR (ρ_f).

If the pressure of aqueous vapour in air at a pressure b mm. (temperature $t°$) is e mm., the partial pressure of the dry air is $b-e$ mm. Whence (§ 6*f*)

$$\rho = \rho_0 \frac{b-e}{760}\frac{1}{1+at};$$

$$f = \tfrac{5}{8}\rho_0 \cdot \frac{e}{760}\frac{1}{1+at};$$

and, since $\rho_f = \rho + f$, it follows further that

$$\text{(11)} \qquad \rho_f = \frac{\rho_0}{760}\frac{b-\tfrac{3}{8}e}{1+at}$$

$$= 0{\cdot}001702\,(b-\tfrac{3}{8}e)\,\frac{1}{1+at}\left(\frac{\text{kilograms}}{\text{cubic metre}}\right).$$

§ 10. ADIABATIC PROCESSES.

The quantity of heat necessary to raise the temperature of a kilogram of a gas 1° C. depends on the method of applying the heat, and is termed the specific heat of the gas. If during the warming process the pressure is kept constant, we will call the specific heat C_p, while we will designate by C_v the specific heat at constant volume, both being measured in calories per kilogram.

It is found that

(12) $$C_p - C_v = \frac{R}{423 \cdot 5},$$

where $423 \cdot 5$ = mechanical equivalent of the calorie in kilogram-metre gravitation units.

The quotient $\frac{C_p}{C_v}$ will be denoted by k.

The velocity of propagation of a pressure disturbance (or the velocity of sound), u, in a gas is related to k, and to the height of the homogeneous atmosphere according to the equation:

(13) $$u = \sqrt{g.k.\mathrm{H}} = \sqrt{g.k.\frac{p}{\rho}} = \sqrt{g.k.\frac{p_0}{\rho_0}(1+\alpha t)}\left(\frac{\text{metres}}{\text{second}}\right).$$

(For values of C_p, C_v, k, and u, see Table VII. of gas constants.)

If a gas whose state is defined by ρ_1, v_1, t_1, p_1, is brought adiabatically into the condition defined by ρ_2, v_2, t_2, p_2 (that is to say, the gas is protected against any exchange of heat with surrounding bodies), the following equations hold for the transformation:

(14) $$p_2 v_2^k = p_1 v_1^k.$$

(15) $$\frac{p_2}{\rho_2^k} = \frac{p_1}{\rho_1^k}.$$

(16) $$v_2^{k-1}(273 + t_2) = v_1^{k-1}(273 + t_1).$$

(17) $$\frac{273 + t_2}{\rho_2^{k-1}} = \frac{273 + t}{\rho_1^{k-1}}.$$

(18) $$\frac{(273 + t_2)^k}{p_2^{k-1}} = \frac{(273 + t_1)^k}{p_1^{k-1}}.$$

We can deduce from equation (18) the cooling which a mass of gas (air) undergoes when it rises in the atmosphere. If a gas of specific gravity s alters its level by a height Δh, reckoned

from any level in the atmosphere, the resulting alteration in temperature $\Delta t°$ is given by

(19) $$\Delta t = -\frac{1}{423 \,.\, C_p \,.\, s} \cdot \Delta h.$$

For dry atmospheric air $\dfrac{1}{423 \,.\, C_p \,.\, s} = \dfrac{1}{100{\cdot}5} = 0{\cdot}00995.$

(The formula fails as soon as the moist air is reduced in temperature to the dew point. The quotient $C_p \cdot s$ has approximately the same value for hydrogen or coal gas as for air, so that the temperature gradient $\dfrac{\Delta t}{\Delta h}$ can be taken with sufficient accuracy as $-0{\cdot}01$ degrees per metre for these gases also.

§ 11. FLOW OF GASES.

Suppose we have, contained in a vessel, a gas of density ρ_1, under a pressure p_1, and at a temperature t_1, and allow the gas to flow through an opening of q square metres cross section into a space in which the pressure is p; we require to calculate the velocity of flow U of the gas through the opening, and the quantity M of gas which flows through per second. A pressure p_k must first be found which bears to the pressure p_1 the relation

(20) $$p_k = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} p_1 .$$

The value of the factor $\left(\dfrac{2}{k+1}\right)^{\frac{k}{k-1}}$ is 0·53 (very nearly) for air, hydrogen, or coal gas, and 0·54 for carbon dioxide.

Case 1.—p is less than p_k. In this case the rate of flow is *absolutely independent* of the external pressure p, and is given by

(21) $$U = \sqrt{\frac{2}{k-1}} \,.\, u_1 \,.\, \sqrt{1 - \left(\frac{p_k}{p_1}\right)^{\frac{k-1}{k}}} \left(\frac{\text{metres}}{\text{second}}\right).$$

(22) $$M = \sqrt{\frac{2}{k-1}} \,.\, u_1 \,.\, q \,.\, \rho_1 \,.\, \sqrt{\left(\frac{p_k}{p_1}\right)^{\frac{2}{k}} - \left(\frac{p_k}{p_1}\right)^{\frac{k+1}{k}}} \left(\frac{\text{kilograms}}{\text{second}}\right),$$

where u_1 represents the velocity of sound in the gas in the containing vessel (*cf.* equation 13). The gas passes through the opening with the velocity of sound in the gas just at the opening.

Case 2.—p is greater than p_k. In this case the rate of flow of

the gas and the outflow itself depend on p, and are determined by the equations :

$$(23)\quad U=\sqrt{\frac{2}{k-1}}\cdot u_1\cdot\sqrt{1-\left(\frac{p}{p_1}\right)^{\frac{k-1}{k}}}\left(\frac{\text{metres}}{\text{second}}\right).$$

$$(24)\quad M=\sqrt{\frac{2}{k-1}}\cdot u_1\cdot q\cdot\rho_1\sqrt{\left(\frac{p}{p_1}\right)^{\frac{2}{k}}-\left(\frac{p}{p_1}\right)^{\frac{k+1}{k}}}\left(\frac{\text{kilograms}}{\text{second}}\right).$$

If the flow of the gas takes place under a *very small difference of pressure* (as in the case of a balloon valve), the processes can be treated as isothermal ones, and we obtain the simplified formulæ :

$$(25)\qquad U=\sqrt{2gH_1}\,.\sqrt{\frac{p_1-p}{p_1}}\left(\frac{\text{metres}}{\text{second}}\right).$$

$$(26)\qquad M=\sqrt{2gH_1}\,.\,q\,.\,\rho_1\sqrt{\frac{p_1-p}{p_1}}\left(\frac{\text{kilograms}}{\text{second}}\right).$$

(H_1 = height of the homogeneous atmosphere for the gas in the containing vessel.

$\sqrt{2gH_1}$ has the value 396 $\sqrt{1+\alpha t}$ metres per second for air.

Since H is inversely proportional to the specific gravity of a gas, we may use the more convenient formulæ :

$$(27)\qquad U=\frac{396}{\sqrt{s}}\sqrt{\frac{p_1-p}{p_1}}\sqrt{1+\alpha t_1}\left(\frac{\text{metres}}{\text{second}}\right).$$

$$(28)\quad M=\frac{396}{\sqrt{s}}\cdot q\cdot\rho_1\sqrt{\frac{p_1-p}{p_1}}\sqrt{1+\alpha t_1}\left(\frac{\text{kilograms}}{\text{second}}\right).$$

It is often convenient to express the pressures in millimetres of water (see Table XII.).

§ 12. DIFFUSION AND OSMOSIS.

If a division wall, separating two different gases at the same temperature and pressure, is removed without disturbing the equilibrium of the gases, the gases gradually mix together by *diffusion.* The one gas diffuses into the other according to laws similar to those governing the diffusion of heat in a conducting body. The rate of diffusion depends on a certain *coefficient of diffusion* exactly as the rate at which heat diffuses depends on the conductivity of the body. This coefficient has the dimensions cm.^{2} sec^{-1} on the c.g.s. system of units. It increases as the square root of the absolute temperature, and is inversely proportional to the total pressure of the gases, so that the rate of

mixing increases with a rise in temperature or a decrease in the pressure. At 0° C. and atmospheric pressure the following are the coefficients of diffusion for the mixtures given, measured in cm.^{2} sec^{-1}:—

	Carbon dioxide	– air,	= 0·1423
	Carbon dioxide	– oxygen,	= 0·1802
	Carbon dioxide	– hydrogen,	= 0·5437
	Oxygen	– hydrogen,	= 0·7217
	Oxygen	– nitrogen,	= 0·1710
At 18° C.	Aqueous vapour	– air,	= 0·2475
	Aqueous vapour	– carbon dioxide,	= 0·1554
	Aqueous vapour	– hydrogen,	= 0·8710

Note.—The coefficient of diffusion of a gas A in a gas B is identical with that of the gas B in the gas A.

These diffusion processes take place even through a thin rubber membrane showing no pores whatever; this process is called *osmosis*. The relative velocities with which various different gases penetrate into a vacuum through a rubber membrane are given in the following table:—

Gas.	Relative osmotic velocity.	Time necessary for the osmosis of a certain volume of gas.
Nitrogen,	1·00	13·59
Carbon monoxide,	1·11	12·20
Air,	1·15	11·85
Ethylene,	2·15	6·33
Oxygen,	2·56	5·32
Hydrogen,	5·50	2·47
Carbon dioxide,	13·59	1·00

If the rubber membrane separates two different gases, each gas diffuses through the rubber with a velocity proportional to the corresponding number given above, and the composition of the gas on either side of the membrane alters accordingly.

B.—TECHNOLOGY OF GASES.

By JOSEF STAUBER,
Oberleutnant im k. und k. Festungsartillerie Regiment No. 2.

§ 1. All gases which are lighter than air are in theory suitable for filling balloons.

In practice the following are unsuitable :—

Ammonia gas, because it attacks the material of the balloon.
Carbon monoxide, on account of its poisonous character.
Helium, on account of its dearness.

The following gases may be used :—

Hydrogen.
Water gas.
Hot air.
Coal gas.

§ 2. METHODS FOR THE PRODUCTION OF HYDROGEN.

(*a*) By the decomposition of water
  (1) electrically,
  (2) by the passage of steam over glowing iron.

(*b*) By the action of iron or zinc in the cold, on sulphuric or hydrochloric acid.

(*c*) By the decomposition of slaked lime
  (1) by carbon,
  (2) by zinc.

§ 3. THE PREPARATION OF HYDROGEN ELECTROLYTICALLY.

The cost of the plant required and of production is great, and the method only pays when cheap power can be employed for the production of the electric current, and when the oxygen, simultaneously produced, can be advantageously disposed of.

It is necessary to have

(1) A shunt-wound direct-current dynamo.

(2) The electric current led through a series of electrolytic cells for the decomposition of the water.

(3) Means for making the water conducting. Caustic soda, caustic potash, potassium carbonate, and dilute sulphuric acid are frequently used for this purpose.

(4) A potential difference of at least 1·5 volts ; on account of the increase of resistance at the electrodes it is preferable to allow 2·5 volts.

This voltage does not hold for pure water. For technical purposes the water is made a better electrolyte by the addition of alkalis or acids. The choice of electrolyte depends on the nature of electrodes to be used.

With iron electrodes the hydrates or carbonates of the alkali metals are used; with lead electrodes only dilute sulphuric acid is employed. In the latter case the high conductivity enables a large current density to be used, thereby reducing the cost of the process.

Iron electrodes enable a lighter and stronger apparatus to be used, but a smaller current density.

(5) A current density of 14 ampères per 100 sq. cm. of the surface of the electrodes. 1 amp. – hour yields 0·037 gm. hydrogen, so that for the production of 1 cb. m. hydrogen and ½ cb. m. oxygen 6 kilowatt hours are necessary.

Example.—Given a 100 H-P. dynamo giving 60 kilowatts at 100 volts. The iron electrodes are 30 cm. × 50 cm., *i.e.* 1500 sq. cm. area.

If we send (see (5)) $14 \times 15 = 210$, or say 200 amps., through the water, we need $\frac{600 \text{ (amp.)}}{200} = 3$ rows of cells. The number of cells in each row works out to be $\frac{100 \text{ (volt.)}}{2 \cdot 5} = 40$, so that the total number of cells $= 3 \times 40 = 120$.

Now, every amp.-hour yields 0·037 gm. hydrogen per cell. Since 200 ampères pass through each cell, we obtain altogether $0 \cdot 037 \times 120 \times 200 = 888$ gm. hydrogen per hour, or, roughly, 10 cubic metres. We obtain the same result if we take 6 kilowatt-hours as necessary for the production of 1 cb. m. hydrogen (see (5)). Since we have 60 kilowatts at our disposal, we obtain hourly $\frac{60}{6}$ (kilowatts) or 10 cb. m. hydrogen.

Sixty hours will be required to fill a balloon of 600 cb. m. contents.

Description of apparatus for electrolysis of water. — The apparatus of Dr Oscar Schmidt of Zurich consists of a row of cells arranged in series. The electrodes are cast-iron plates formed after the manner of the chambers of a filter-press (see fig. 1). The electrodes are separated by non-conducting diaphragms, so that the oxygen and hydrogen may be collected separately. The liquid is a weak solution of potash which undergoes no change in the process, but the decomposed water must be replaced by fresh distilled water from time to time. The liquid is kept in constant circulation by the development of the gas on the surfaces of the electrodes, and a certain amount of the liquid is carried over as spray with the gas into the gas refiner, where it is separated from the gas, and flows back into the chambers of the apparatus.

The gases can be led away under a pressure up to that of 1 metre of water.

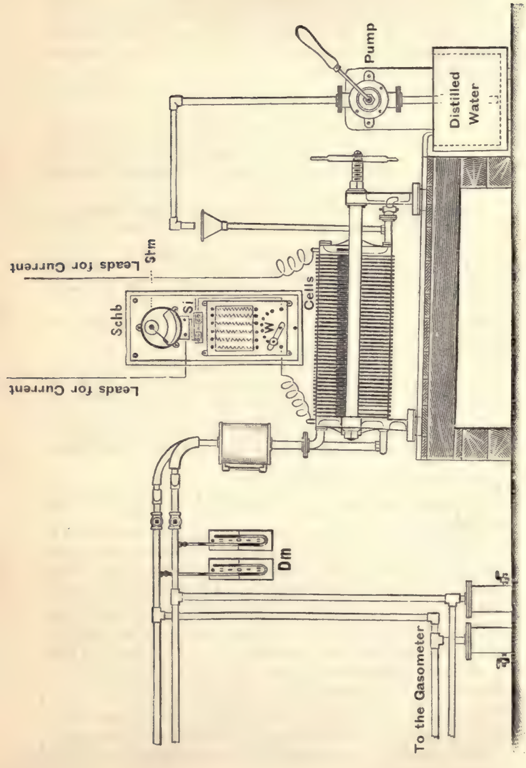

FIG. 1.—Dr Schmidt's apparatus for the electrolysis of water.

During the working, only pure water need be admitted into the apparatus.

One apparatus produces 168 litres hydrogen mixed with about 1 litre of oxygen. As a rule, the hydrogen produced is some 25 per cent. heavier than pure hydrogen, weighing $0{\cdot}08 + \frac{25}{100} \times 0{\cdot}08 = 0{\cdot}1$ kg. per cb. m.

Arrangement of the apparatus.—The electric circuit (see sketch) passes through the switchboard *Schb*, to which is attached a safety fuse *Si*, an ammeter *Stm*, and a small rheostat W; pressure gauges, *Dm*, are attached to the mains leading to the gasometer.

The apparatus is constructed for use either with voltages of 65, 110, or 200, and can be built to absorb 30 kilowatts.

The cost of hydrogen produced by this method depends principally on the cost of the current: on an average it may be taken as about 4d. to 8d. per cubic metre.

§ 4. PREPARATION OF HYDROGEN BY THE PASSAGE OF STEAM OVER GLOWING IRON.

Water can be decomposed by bringing it into contact with a body such as glowing iron, for which oxygen has a greater chemical affinity than it has for hydrogen.

The chemical reaction takes place according to the following equation:—

$$3Fe + 4H_2O = Fe_3O_4 + 4H_2.$$

From this it follows that 1881 gm. Fe and 806 gm. H_2O are necessary for the preparation of 1 cb. m. hydrogen.

This method has been advocated by

1. Coutelle. 2. H. Giffard. 3. Dr Strache.

(1) **Coutelle's method.**—Introduced in 1793 by the French aeronauts. Seven long iron (or, better, copper) retorts were arranged in two layers in a brick oven. The tubes were filled with rust-free iron filings, and both ends closed by covers well cemented on. Through one cover a small tube passed to admit the steam, while the gas was conducted away by a tube in the opposite cover. The gas is led through a bottle of lime water directly into the balloon. The fire must be sufficient to keep the iron at a white heat for about forty hours to fill a balloon of 450 cb. m. capacity.

(2) In **Giffard's arrangement** coke is first oxidised in a suitable generator by blowing in air. The resultant generator gas (mostly carbon monoxide) is freed from fine ash by passing it through a specially arranged purifying tower filled with fire-proof material, and is then passed through a special form of retort filled with specular iron ore. The oxide of iron is simultaneously

heated and reduced to metallic iron by the hot furnace gas ; steam is now blown into the retort and oxidises the iron to Fe_3O_4, setting free hydrogen. The generator gas is led into this muffle once more, the oxide is reduced, and so the whole process is repeated.

Disadvantages of this method for practical industrial application.—The charge of iron soon becomes useless owing to the formation of ferrous sulphate, due to the presence of sulphur iu the coke. This covers the material with a protective layer, and moreover easily melts, causing the whole charge to bake into a hard solid mass.

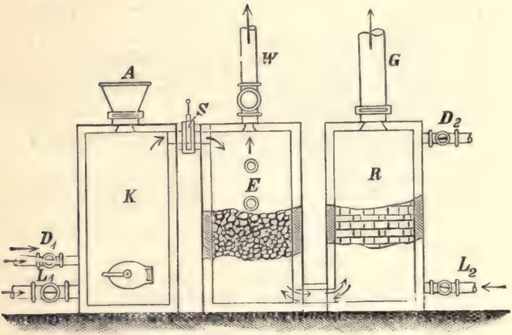

FIG. 2.—Dr Strache's hydrogen generator.

(3.) **Dr Strache** has lately succeeded in overcoming the difficulties of Giffard's method by the use of charcoal instead of coke. The use of the purifying tower to remove any ash or dust is in this case unnecessary, and in addition the carbon monoxide not used up in the reduction of the iron is burnt in a regenerator, thus supplying the heat necessary to superheat the steam required.

Dr Strache's apparatus comprises the chambers K (see fig. 2) containing the charcoal, E filled with iron filings, and R the regenerator.

After a fire has been made in K, this is fed with charcoal, and the chamber E filled with iron filings ; air is then blown into the chamber K by means of the fan L_1. The generator gas is drawn into the chamber E, where it heats the iron, and at the same time reduces any oxides present to metallic iron. The

remaining carbon monoxide is burnt in the regenerator R by air forced in through the fan L_2, and the fire-bricks contained in the regenerator are thus raised to a white heat, while the spent gas (carbon dioxide) escapes through the chimney G. Next the steampipe D_1, the valve S, and the chimney G are closed, the pipe W is opened, and steam is blown in through the tube D_2; this becomes strongly superheated in the regenerator, and in the chamber E produces hydrogen gas and oxide of iron. The gas escapes through the tube W, mixed with the residual steam, which is completely condensed in a scrubber.

The hydrogen thus produced needs no further purification. As soon as the production of gas has nearly stopped, which occurs after a short time, the oxide of iron is again reduced and heated by blowing air in through L_1. As soon as the iron glows brightly again, the production of the gas is once more started, and so the process continues.

By this method the apparatus is kept continuously working with the minimum expenditure of heat, while the oxide of iron is constantly being reduced to metallic iron. The cost of hydrogen manufactured by this method is about 1d. per cubic metre.

In order to get an idea of the rate of production of the gas with this apparatus, the following table, published by the "Internationale Wasserstoff Aktien-Gesellschaft," has been added:—

EXPERIMENTAL DATA.

No. of investigation.	Date, 1899.	Kind of coal used.	Length of experiment in hours.	Number of charges.	Number of kg. of material burnt.	Number of cubic metres of gas produced.	Rate of production of gas in cubic metres per hour.	Mean quantity of gas produced per charge in cb. m.	Amount of combustible material in kg. required per 1 cb. m. of gas.	Kg. carbon used for 1 cb. m. gas.	Volume of gas in cb. m. obtained for 1 kg. carbon.
1	2 Oct.	Graz Gas Coke	7·0	25	85	211	30	8·4	0·40	0·36	2·78
2	1 Oct.		7·0	29	110	239	34	8·2	0·46	0·41	2·44
3	11 Oct		7·0	30	127	197	28	6·6	0·64	0·45	2·22
4	7 Oct.		4·5	16	77	135	30	8·4	0·57	0·40	2·50
5	7 Oct.	Upper Silesian coal	6·5	28	134	213	33	7·6	0·63	0·44	2·27
6	6 Oct.		4·5	20	96	175	39	8·7	0·55	0·38	2·63
7	8 Oct.		4·0	21	77	158	39	7·5	0·49	0·34	2·94
8	14 Oct.	Buchberg coal	5·0	27	216	212	42	7·8	1·02	0·53	1·90

§ 5. PREPARATION OF HYDROGEN BY THE ACTION OF IRON OR ZINC ON SULPHURIC ACID OR HYDROCHLORIC ACID.

Rust-free iron filings, or granulated zinc, react in water acidified slightly by either of the above acids, according to the following chemical equations:—

$$(a)\quad \text{Iron}: H_2SO_4 + Fe = H_2 + FeSO_4,$$
$$(b)\quad \text{Zinc}: H_2SO_4 + Zn = H_2 + ZnSO_4;$$

or if we use HCl instead of H_2SO_4:

$$(a)\quad \text{Iron}: 2HCl + Fe = H_2 + FeCl_2,$$
$$(b)\quad \text{Zinc}: 2HCl + Zn = H_2 + ZnCl_2.$$

The use of hydrochloric acid would appear to be more advantageous than that of sulphuric acid, since for an equal weight of zinc or iron only 73 parts by weight of HCl are needed as against 98 parts of H_2SO_4 in order to obtain 2 parts of hydrogen.

Commercial sulphuric acid is, however, usually much more concentrated than commercial hydrochloric acid, so that the weight of common hydrochloric acid required for the production of a given weight of hydrogen is much greater than the weight of ordinary concentrated sulphuric acid. In addition, hydrochloric acid vapour is not only injurious to the health, but also to the fabric of the balloon, and it is difficult to prevent some being carried over with the hydrogen into the balloon. On these grounds the use of hydrochloric acid in the preparation of hydrogen is not to be recommended.

The question as to whether the use of zinc or iron is the more advantageous is easily settled by reference to the above formulæ. In order to get 2 parts by weight of hydrogen, we need 65 parts of zinc as against 56 parts of iron. Further, zinc is much dearer than iron and usually contains arsenic as an impurity, which, in the course of the preparation of the hydrogen, causes the formation of arsenuretted hydrogen (AsH_3), a very poisonous gas. The use of zinc, then, is not to be recommended, although the rate of development of the gas is greater with it than with iron. According to Millon, the addition of $\frac{1}{1000}$ part of platinic chloride to the acid solution accelerates considerably the rate of evolution of gas. The apparatus in which the chemical reaction takes place may be constructed

(*a*) On Charles' system.
(*b*) On Giffard's or Renard's system.

(*c*) On Lieut. Stauber's system, depending on the principle of continuous circulation, but with the modification that the water and acid are added separately.

The apparatus used for the production of hydrogen in the wet way usually consists of several lead-lined vessels—so-called generators—in which the chemical action takes place. The impure gas containing acid fumes is led out into a washing chamber, where it comes into contact with a continuous stream of water, which cools the gas and removes the greater part of the acid. Afterwards the gas passes through drying vessels filled with burnt lime, calcium chloride, or caustic potash, which remove practically the whole of the moisture, and it is afterwards led directly into the mouth of the balloon.

Modern forms of gas producers give 100 to 150 cubic metres per hour and can be worked continuously. When working economically, 5 kg. H_2SO_4 and 3·5 kg. Fe are necessary for the production of 1 cb. m. of hydrogen. In a poor apparatus, 6 to 7·5 kg. H_2SO_4 and 4 to 5 kg. Fe may be necessary for the production of the same quantity of gas.

(*a*) **Charles' arrangement.**—The raw materials necessary for the preparation of the gas are brought into a wood- or lead-lined iron vessel in which the chemical action occurs. As soon as the production of gas ceases, the lid of the vessel is removed, the acid liquor drained off, the iron well washed with water and more iron added, the lid closed again, and the acid solution allowed to flow in.

Such a form of apparatus has the disadvantage that the iron filings become coated with a layer of ferrous sulphate, owing to the rapidity with which the gas is evolved and the want of motion of the liquid, and this prevents the further action of the acid, rendering such an apparatus of little practical utility.

(*b*) The disadvantages of the method are overcome by the application of Giffard and Renard's principle of continuous circulation, acid flowing in at one side of the generator while the ferrous sulphate liquor flows out continuously at the opposite side.

An apparatus arranged in this manner has the one disadvantage that the quantity of acid required to generate 1 cb. m. of hydrogen may be as much as 10 kg.

In general, lead-lined iron generators require extremely careful handling: the lead is readily attacked by warm sulphuric acid, and also has a greater linear coefficient of expansion than the iron vessel surrounding it, this often causing the lead lining to blister in consequence of the high temperatures developed by the chemical action. When this occurs, the lead is frequently pierced by the sharp iron filings, allowing the acid to percolate

into the space between the lead coating and the iron vessel; this very quickly ruins the apparatus.

If the lid of the vessel is made airtight by water, this must be provided with exit taps, and the water must be constantly renewed.

The formation of a layer of ferrous sulphate on the surface of the iron filings is prevented by the circulation of the liquid and the high temperature due to the rapid development of the gas; the more so if the generator is constructed of a badly conducting material such as wood.

(*c*) The raw materials are still more thoroughly used up if the sulphuric acid and the water are admitted into the generator by separate openings. (Stauber's Apparatus. Austrian patent No. 6507, by Messrs Dolainski.)

§ 6. DECOMPOSITION OF SLAKED LIME BY COAL.

This method has been applied practically, but is no longer in general use. The mixture of lime and coal must be warmed in retorts heated externally, and after the reaction has ceased the retorts must be emptied and recharged. The combustible material is here, as in all retort processes, completely spent and useless afterwards, which is extravagant and an important consideration when cheap hydrogen is required.

The reaction progresses according to the following equation:—

$$H_2O + Ca(OH)_2 + C = CaCO_3 + 2H_2;$$

but may be looked upon as taking place in two stages:

(1) $2H_2O + C = CO_2 + 2H_2$.

(2) $CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$.

In all methods of obtaining hydrogen from water by the formation of carbon dioxide and the absorption of this by lime, it is to be noted that according to the first equation 44 kg. CO_2 are formed along with 4 kg. hydrogen, and to absorb this quantity of CO_2 we require in practice 90 kg. lime, so that 2 kg. lime are required per cubic metre of hydrogen, which makes the method very expensive. The method is not to be recommended for the preparation of hydrogen on a large scale, so long as no simple method exists of reconverting the powdered chalk formed into lime.

§ 7. DECOMPOSITION OF SLAKED LIME BY ZINC.

Method used by Dr Wilhelm Majert and Lieutenant Richter.
German Patent No. 39898 (see fig. 3).

This method is based on the behaviour of zinc dust when heated with various hydrates. The hydrate is decomposed by

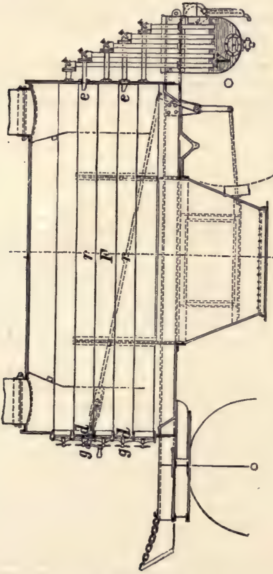

FIG. 3.—Majert-Richter hydrogen generator.

the zinc, hydrogen and zinc oxide being formed. The best materials for the purpose are calcium hydrate, hydrated cement, aluminium hydrate, or calcium chloride combined with two molecules of water of crystallisation.

The formation of the hydrogen takes place in two stages, the

first of which occurs at a dark red heat, the second at a bright red heat. The following equations represent the reactions which take place :—

I. First phase :

$$2Ca\begin{matrix}\diagup OH\\ \diagdown OH\end{matrix} + 2Zn = Ca_2\begin{matrix}\diagup OH\\ = O\\ \diagdown OH\end{matrix} + Zn + ZnO + H_2.$$

Half the available hydrogen is given off at this stage, and remaining is a mixture of

(1) A new calcium hydroxide which has not yet been thoroughly investigated, but which is readily obtained by a prolonged heating of ordinary calcium hydroxide at a dull red heat.

(2) Zinc oxide.

(3) Zinc dust.

II. Second phase :

$$Ca_2\begin{matrix}\diagup OH\\ = O\\ \diagdown OH\end{matrix} + Zn + ZnO = 2CaO + 2ZnO + H_2.$$

Finally a mixture of calcium and zinc oxides is left. For a rapid development of hydrogen it has been found better in practice to discontinue the reaction before the whole of the hydroxide has been decomposed, so that small quantities of calcium hydroxide and of zinc dust remain at the end of the process.

The mixture of zinc dust and the hydroxide is placed in lead boxes (cartridges) and soldered up. The substances are mixed in such a proportion that one molecule of zinc dust is present for each molecule of available water (in the hydroxide). If calcium hydroxide containing uncombined water is used it must be mixed with fine quicklime, so that one molecule of quicklime is present for each molecule of uncombined water. An apparatus designed for continuous working is shown diagrammatically in the accompanying figure. A system of 20 tubes is arranged in the space F, which can be heated by a furnace underneath. At one end of each tube *r* is attached a pipe *e* to conduct away the gas, terminating in the hydraulic receiver V, while the other end of *r* is closed by a lid *d*, held in position by a screw *g*. The whole apparatus can be mounted on a waggon and used in the open air. The rate of development of the gas is such that about five hours are required to fill a balloon of 600 cb. m. contents, using two such sets of retorts, but the cost of the method is very considerable indeed.

§ 8. WATER GAS.

The preparation of water gas is similar in many ways to the preparation of hydrogen by Strache's method, described above.

Water gas is colourless and odourless. Its mean specific gravity with respect to air is 0·54, with respect to hydrogen, 7·82.

Its composition is as follows:—

Constituent.	Percentage volume.
H_2,	50
CO,	40
N_2,	5
CO_2,	4
O_2,	0·7
CH_4,	0·3
Total,	100

A mixture of water gas and air is explosive.

Phenomenon	Per cent. volume of water gas present.
Commencement of visible burning,	11
Continuous spreading flame,	14
Audible explosion,	18
Maximum explosion,	31

Water gas is formed by the decomposition of steam by glowing charcoal. The products of decomposition depend upon the temperature: at a high temperature carbon monoxide and hydrogen are formed, while at lower temperatures carbonic acid and hydrogen are produced. The decomposition of the steam goes on continuously so long as the temperature is kept sufficiently high.

We have then:

(1) $C + 2H_2O = CO_2 + 2H_2$ at low temperatures.

(2) $C + H_2O = CO + H_2$ at high temperatures.

In the first case we obtain 33·3 per cent. by volume of CO_2, or 0·65 kg. per cubic metre of the mixtue of gases, requiring for its absorption about 1 kg. lime.

Furthermore, at low temperatures much of the steam is carried over undecomposed. A high temperature is then an absolutely necessary condition for the production of water gas, bringing about not only the complete decomposition of the steam, but also preventing the formation of large quantities of carbon dioxide. 12 kg. of carbon with 18 kg. steam produce 30 kg. of water gas.

The apparatus (fig. 4) consists of a brick-lined producer or generator, which is filled with coke through the feeding hopper E, which can be doubly closed. When the combustion has been

started air is driven into the apparatus at the lower end A, and sweeps through the generator, heating the coke to a very high temperature. The producer gas formed escapes through the

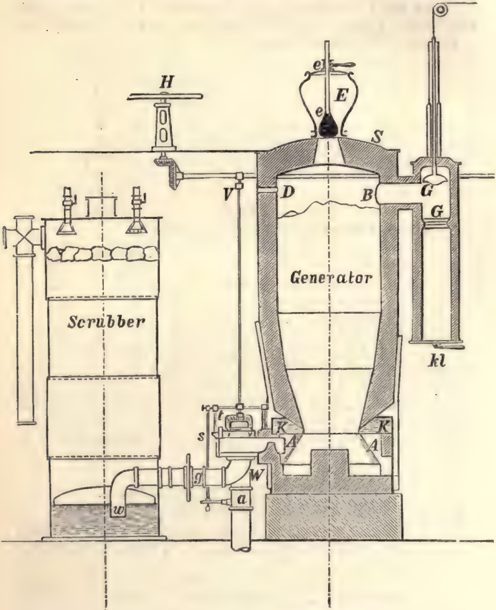

FIG. 4.—Dr Strache's water-gas generator.

opening B and the valve G G. The entrance of air from outside through the latter is prevented by a water trap, but it is free to allow gas to pass out. Underneath the valve the tube is continued, and the greater part of the dust and ash carried over settle in it. It can be cleared out by opening the cover *kl*.

The producer gas escapes under the conical valve, and is led directly away to where it is required for eventual use.

In order to break up and so facilitate the removal of the dross which makes its way to the lower part of the generator, it must be rapidly cooled. The European Water-gas Company have a circular trough of water, K, around the lower part of the generator, but this is hardly necessary unless the combustible material used possesses a great percentage of ash. The openings left for the removal of this ash are closed by air-tight Morton doors.

As soon as the temperature has become high enough for the favourable production of water gas (according to Bunte about 1200° C.), this first or blowing-up process is stopped, the conical valve G is closed, and simultaneously a slide *s*, which permitted the air-blast to enter the generator, is moved so that the air is now cut off, while at the same time a tube which serves to conduct away the water gas formed is connected on to the lower part of the generator. The movements of both the valve G and the slide *s* are effected by turning the wheel H. As soon as this is done a steam cock is opened which allows a steam-blast to enter the upper half of the generator at D. This steam blast passes through the generator from the top to the bottom and so comes into contact with coke at higher and higher temperatures as it makes its way down. The water gas escapes, through the opening mentioned, in a heated condition, and is cooled by passing through a scrubber filled with coke, which also serves to remove any ash carried over. The material is heated for 10 minutes by air, then steam is passed in for 5 minutes. A generator holding 600 kg. coke will give 20 cb. m. of water gas in this 5 minutes or 80 cb. m. per hour.

§ 9. HOT AIR. (Montgolfier's Gas.)

Heated air was first applied to the inflation of balloons by the brothers Montgolfier. Montgolfier gas consists of a mixture of heated air, the light gaseous products of the fuel, and of water vapour.

Rules for inflating a balloon with Montgolfier gas :

(1) The gas is most readily produced from straw, which must burn rapidly with a bright sharp flame. Vines, roots, and all materials giving off sparks are unsuitable, although they may generate a great heat.

(2) At different places among the burning straw pieces of the finest possible wool must be thrown in order to retard the development of smoke.

(3) Too much straw must not be lighted at once, but only small quantities. This must be especially remembered when laying on more straw.

(4) The mouth of the balloon will be driven about by the current of air due to the fire, so that it must be protected from the fire and fastened down.

(5) The mouth must be so arranged that all the air which enters it passes by the fire and so gets heated.

§ 10. THE PRODUCTION OF COAL GAS.

Coal gas is manufactured by the dry distillation of coal.

The raw material is submitted to dry distillation in hermetically closed retorts. The gas begins to be given off at a temperature of 100° C. At higher temperatures more gaseous and easily volatile liquid hydrocarbons are given off, which split up into simpler hydrocarbons at still higher temperatures, in the presence of the carbon. At a white heat (1300° C.) the sulphur present in the coke is driven off, and the purification of the gas thereby rendered more difficult, so that it is best to maintain a temperature of about 1000° C., *i.e.* a bright red heat.

The length of time required for the distillation is usually about four hours for a good charge, but for soft coal six hours may be necessary. The amounts and specific gravities of the gas given off at different periods during the distillation from 1000 kg. coal in a typical example were as follows:—

In the 1st hour	124 cb. m.	gas of specific gravity,	0·533.
,, 2nd ,,	85	,, ,,	0·410.
,, 3rd ,,	84	,, ,,	0·327.
,, 4th ,,	13	,, ,,	0·268.
Total,	306 cb. m.		

The composition of the gas at the different stages of the manufacture is, according to Dr Tieftrunk, as follows:—

	Hour of distillation.				
	1	2	3	4	5
	Percentage volume.				
Heavy hydrocarbons,	13	12	12	7	0
Marsh gas,	82	72	58	56	20
Hydrogen,	0	8·8	16	21·3	60
Carbon monoxide,	3·2	1·9	12·3	11	10
Nitrogen,	1·3	5·3	1·7	4·7	10

From this table we see that the quality of the gas evolved in the fifth hour is best from the point of view of the aeronaut, since this contains the largest proportion of hydrogen, and has consequently the greatest lifting power.

The coal used must be as dry as possible: when moist coal is used greater quantities of carbonic acid gas are always produced.

The chief impurities of coal gas, leaving out of consideration small quantities of cyanogen compounds, are:

(1) Gaseous carbonic acid (CO_2).

(2) Gaseous sulphuretted hydrogen (SH_2).

(3) Ammonia (NH_3).

The amount of carbonic acid gas present in the coal gas undergoes practically no change in its passage through the condensers, the scrubber and washing apparatus, and if iron is used in the process of purification may actually have, after the cleansing, increased by 10–18 per cent. of the quantity originally present. This is due to the action of the sulphates in the purifying reagents on the ammonium carbonate.

The ammonia decreases rapidly in amount from the hydraulic main onwards. The gas should not contain more than 30–50 gm. ammonia per 100 cb. m. before the cleansing processes, if these are to be carried on satisfactorily. A little ammonia is added during the dry cleansing process, but only in the form of salts, which are removed by the mechanical action (filtration) of the cleansing material, and the last traces are removed by combination with the sulphates present in the materials used.

(2) **The hydraulic main.**—This is constructed either of wrought iron or of sheet iron, and has a cylindrical or a V-shaped cross section. The ends of the upright tubes dipping in to the water should be 200 mm. distant from the floor of the main, and should only just be immersed 20 to 30 mm. with an exhauster, or without an exhauster 50 to 72 mm., according to the pressure in the gas-holder.

The surface of the liquid acting as the trap should have at least ten times the area of the ends of the tubes dipping into it.

(3) **The condensation.**—The gas leaving the hydraulic main has a temperature of from 70° C. up to (rarely) 100° C., and must be cooled down to a temperature of 10° to 20° C., which causes the greater part of the tar and ammonia to separate out. In small gasworks a stationary tube condenser is the most practical, *i.e.* one in which the gas passes through a number of tubes of 150 to 200 mm. length, going alternately from the bottom to the top and from the top to the bottom, and being cooled by contact with the walls, while the condensation products collect in a vessel underneath and are removed as required.

The horizontal tube condenser is seldom used in modern

works, as it is not very effective and is easily stopped up. The most practical form of condenser for large works is one in which the gas passes through the ring-shaped space between two concentric cylinders, which are so constructed that the distance between the walls is not more than 75 mm., or at most 100 mm.; the inner cylinder must be about this amount less in radius than the outer cylinder, which has usually a diameter of from 800 to 1200 mm. The height of the apparatus varies from 4 to 10 m. If the temperature of the air is so high that the gas cannot be cooled below 12° C., it should be possible to cool it to this temperature, at least, by allowing water at a temperature of 8° to 10° C. to circulate round the cylinders.

(4) **The standard washer-scrubber** may be relied upon to remove the last traces of ammonia from the gas and furnish an excellent ammonia solution for commercial purposes.

A set of thin metal sheets is contained in a cast-iron box, and the gas has to make its way up between the sheets against a stream of water flowing in the opposite direction. As the water and gas are going in opposite directions, the purest water comes into contact with the purest gas.

(5) **The exhauster.**—The pressure in the retorts increases, according to the rate of development of the gas, and becomes greater than that of the external atmosphere, causing considerable quantities of gas to escape through various places where the retort is not gas-tight, and also much of the light-producing part of the gas to be decomposed into carbon and non-luminous marsh gas. This loss of gas can be largely prevented if the pressure in the hydraulic main is kept at about 0 to 10 mm. below atmospheric pressure, and to achieve this an exhauster is used.

The most practical form is Beale's exhauster. This makes 50–100 revolutions per minute according to the rate of gas production, has an efficiency of 70–80 per cent., and requires an engine of 1–2½ horse-power to drive it.

If d_2 represents the diameter of the cylinder, d_1 that of the drum, n the number of revolutions per minute, η the efficiency, then the quantity of gas sucked out by the exhauster per hour: $Qu = 30n\eta\pi(d_2^2 - d_1^2)$.

The use of iron and manganese salts as purifiers has almost completely superseded the use of lime. Originally calcium hydrate was employed in a pulpy or powdery condition.

Formerly Laming's compound was used in the iron method of purifying the gas. It consisted of oxide of iron and gypsum, the former to remove the sulphuretted hydrogen and the latter the ammonia. Since, however, the chemical action of the gypsum is only at best an incomplete one, and, moreover, the ammonium salts are readily removed by mechanical means, this

mode of purification has been abandoned, and now only iron compounds are employed, a natural or artificial hydrated oxide of iron being used. This latter body is known as Deicke's Compound. If this compound is kept in a fine granulated condition, and is not heated too strongly in the process of regeneration, so that it remains hydrate, 10,000 cb. m. of gas may be purified in the course of a year by 1 cb. m. of the compound. The frequent addition of sawdust to the mass, often adopted to loosen it, is not to be recommended, as it only serves its purpose for a short time, and afterwards merely aids the formation of a solid impenetrable mass.

Coal gas was first applied to balloon work by Green, the celebrated English aeronaut.

The specific gravity of coal gas varies according to the amount of heavy hydrocarbons present. It varies between 0·370 and 0·523. Vienna gas, for example, has a specific gravity of from 0·43 to 0·48, according to the coal used in its preparation.

The specific lifting power of coal gas, *i.e.* the lifting power per cubic metre, varies from 0·74 to 0·67 kg. (for Vienna gas).

§ 11. COMPRESSION OF HYDROGEN.

The hydrogen gas, well purified and dried, is collected in a gasometer, and afterwards compressed by means of a suitable compression pump, under a pressure of from 120 to 200 or even 300 atmospheres, into steel cylinders.

The compression pump (compressor) (fig. 5) consists of 2, 3, or even 4 compression cylinders of gradually decreasing volumes. In 3-cylinder compressors the first cylinder contains a piston carrying a piston-rod, while the other two cylinders are constructed as plunge-pumps. The first piston, on its upward stroke, sucks the gas from the gasometer through the valve R, which prevents the backward passage of the gas, and is lubricated by vaseline from the oil-dropping arrangement O.

On the downward stroke of the piston the gas underneath it is compressed and forced into the upper part of the cylinder on the other side of the piston, through the valve S. In the next upward stroke of the piston this gas is again compressed, and escapes through the valve S under a pressure of about 7 atmospheres into the second cylinder, the piston of which is just starting to move upwards. The upward motion of this second piston compresses the gas to about 50 atmospheres, and drives it through the valve D, the cooling tube K, and the valve S, into the third cylinder, which is of much smaller cross section, and is also just now at its lowest point. As the piston is pressed back, the gas is forced through the valve D and the cooling tube

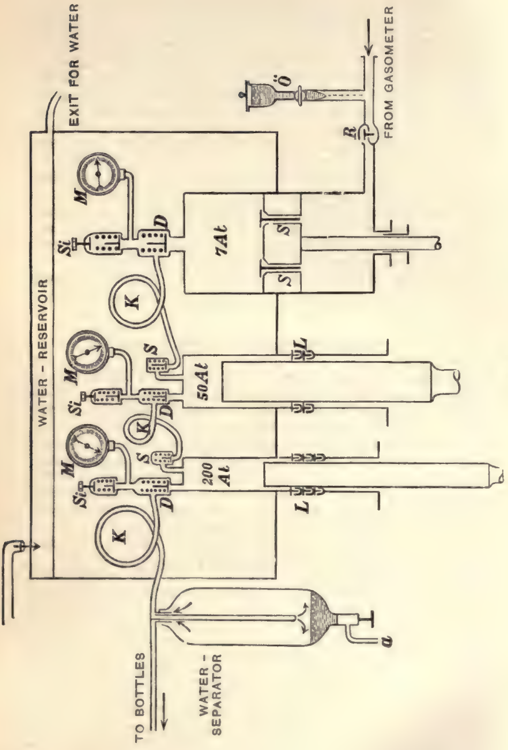
EXIT FOR WATER
FROM GASOMETER
WATER - RESERVOIR
Ö
R
M
Si
D
K
7At
S
50At
200 At
L
TO BOTTLES
WATER - SEPARATOR
a

FIG. 5.

K to the bottom of the liquid separator, where the lubricating oil as well as the remainder of the moisture is condensed and can be drawn off through the tap *a*.

From the upper part of this separator the high pressure mains, to which a suitable manometer is attached, lead directly to the steel cylinders. A pressure gauge M is attached to the top of each cylinder, to which are also fixed suitable safety valves (S_i); the whole of these valves and tubes are cooled by running water. The packing, L, of the pistons consists of leather bands. An engine of 12 H.P. is necessary to drive a 3-cylinder compressor capable of compressing 60 cb. m. per hour to 200 atmospheres pressure.

The leather strips last usually ten to fourteen days, and need a considerable quantity of oil.

The cylinders are either made of seamless tubes after Mannesmann's pattern, or of steel treated by Ehrhard's process. The former are made out of either hard or mild steel, having a breaking tension of 60 kg. per 1 sq. mm., and will stand a working pressure of about 200 kg. per 1 sq. mm., while the latter are cheaper and only intended to bear pressures of from 120 to 150 atmospheres.

The bottom of a Mannesmann's cylinder is made of wrought iron, while the neck is strengthened by a steel ring sweated on to it.

Every cylinder is provided with suitable fittings (valve, etc.). These are constructed of bronze, and close the opening of the cylinder either by means of a celluloid or fibre cone, which is pressed down against the pressure of the gas with a tight-fitting screw, or the pressure of the gas itself in combination with a suitable screw is used to close the aperture, which latter arrangement has the advantage that even if the screw of the valve is shaken during the course of a journey, the whole still remains tight. Gas cylinders intended to hold gas at 200 atmospheres pressure should stand a pressure of 450 atmospheres or a continued pressure of 400 atmospheres without bursting. The testing is effected by means of cold water pressure.

§ 12. THE INFLATION OF BALLOONS.

(*a*) Out of cylinders of compressed gas.
(*b*) Directly from the gas producer in the case of hydrogen, or out of a gasometer in the case of coal gas.

(*a*) This method is usually adopted by military authorities, and invariably when it is inconvenient to use a gas manufacturing apparatus. It is also used when it is advisable to inflate the balloon in the shortest possible time, or where it is desired to

have the balloon ready to be sent off at some particular moment (for a high ascent, for example) This method of inflating the balloon may also be used with advantage when it is not possible to anchor the balloon after it has been inflated.

(*b*) In using coal gas, it is advantageous to have a special pipe leading directly to the gasometer, and to inflate the balloon as near as possible to the gasometer.

Let d = the diameter of the gas pipe in mm.
h = the pressure of the gas in mm. of water.
l = the length of the pipe in metres.
s = the specific gravity of the gas with respect to air.
Q = the "hourly carrying capacity" of the cross section in cubic metres.

then (1) $$Q = 0\cdot0022543\, d^2 \sqrt{\frac{h\,.\,d}{s\,.\,l}}$$

and (2) $$d = 11\cdot449 \sqrt[5]{\frac{Q^2\,.\,s\,.\,l}{h}}.$$

Example 1.—Find the hourly carrying capacity of the cross section of a tube for which

l = 1000 m.
d = 600 mm.
h = 15 mm.
s = 0·4.

Substituting these values in equation 1 we get

$$Q = 0\cdot0022543 \cdot 600^2 \sqrt{\frac{15\,.\,600}{0\cdot4\,.\,100}}$$
$$= 3849\cdot5$$
or, approximately, 3850 cb. m.

Table IX. gives Q = 3850 cb.m. for the above values.

Example 2. A balloon of 1500 cb. m. contents must be filled in 1½ hours. The gas has a specific gravity $s = 0\cdot4$, and is under a pressure of 15 mm. of water. If the shortest pipe possible has a length $l = 1000$ m., find its smallest allowable diameter.

The formula 2 gives

$$d = 11\cdot449 \sqrt[5]{\frac{1000^2\,.\,0\cdot4.1000}{15}}$$

since Q, the hourly quantity passing any cross section, must be

$$= \frac{1500}{1\cdot5}\ \frac{\text{cb. m.}}{\text{hour}} = \frac{\text{1000 cubic metres}}{\text{hour}}.$$

From this it follows that $d = 349\cdot9$ mm.

From Table IX. we find $d = 350$ mm. for the above values.

In calculations using the English system of units we may use the formula given by Prof. Tole ("On the Motion of Fluids in Pipes").

(3) $$Q = 1350\, d^2 \sqrt{\frac{h.d}{s.l}}.$$

In this formula

Q = the number of cubic feet of gas per hour passing through the pipe.
d = the diameter of the pipe in inches.
h = the pressure of the gas in inches of water.
l = the length of the pipe in yards.
s = the specific gravity of the gas with respect to air.

Example 3.—Calculate Q for a pipe 1250 yards long and 10 inches in diameter, for gas of specific gravity $s = 0{\cdot}4$ under a pressure of 2 inches of water.

Substituting these values in equation 3 we get

$$Q = 1350.10^2 \sqrt{\frac{10.2}{0{\cdot}4.1250}} = 27{,}000 \frac{\text{cb. ft.}}{\text{hour}}.$$

Table IX. (see Appendix) gives the hourly capacity for a gas of specific gravity $s = 0{\cdot}4$ for values of l from 25 m. to 3000 m., and for values of d from 40 mm. to 1000 mm., for a pressure of 15 mm. of water.

Use of Table IX. :

(*a*) In order to solve example 1 with the aid of the table, we look down the column headed 600 mm. until we come to the line marked 1000 at the left-hand side, where we find the number 3850, which gives the hourly capacity.

(*b*) If we want to find the hourly carrying capacity, Q, of a pipe for gas of any density s_1, with the help of Table IX., we must multiply the number obtained from the table for $s = 0{\cdot}4$ by the square root of $0{\cdot}4$, *i.e.* by $0{\cdot}6235$, and divide by the square root of the given density s_1 of the gas, *i.e.* we must multiply by

(4) $$k_1 = \sqrt{\frac{0{\cdot}4}{s_1}} = \frac{0{\cdot}6325}{\sqrt{s_1}};$$

so that if the hourly carrying capacity for a gas of this density is Q_1, then

(5) $$Q_1 = Qk_1 \text{ ; or}$$

(6) $$Q_1 = \frac{0{\cdot}6325}{\sqrt{s_1}} Q = \sqrt{\frac{0{\cdot}4}{s}}\, Q.$$

Example 4.—Given the same data as in Example 1, except that $s=0{\cdot}46$ instead of $0{\cdot}4$, find Q_1:

$$k_1=\sqrt{\frac{0{\cdot}4}{0{\cdot}46}}=0{\cdot}9325.$$

From Table IX., if $s=0{\cdot}4, l=1000$ m., $d=600$ mm., $h=15$ mm.,

$$Q=3850,$$

then from equations (5) and (6) for $s=0{\cdot}46$

$$Q_1=0{\cdot}9325 \,.\, 3850 \text{ cb. m.}$$
$$=3590 \text{ cb. m.}$$

(*c*) If we require the hourly carrying capacity, Q_2, of a pipe for a gas under any pressure h_2, with the help of Table IX., the specific gravity of the gas with respect to air being $s=0{\cdot}4$, we find the capacity Q for the gas under a pressure $h=15$ mm. water, and multiply Q by the square root of the given pressure h_2 divided by the square root of 15 ($=3{\cdot}873$), *i.e.* we multiply Q by

(7) $$k_2=\sqrt{\frac{h_2}{15}}.$$

We have then

(8) $$Q_2=Q.k_2=Q\sqrt{\frac{h_2}{15}}=\frac{Q\sqrt{h_2}}{3{\cdot}873}.$$

Example 5.—Given the same data as in Example 1, except that $h=18$ mm., find the hourly carrying capacity Q_2.

From Table IX. we get for the values

$$\begin{aligned} l&=1000 \text{ m.}\\ s&=0{\cdot}4\\ h&=15 \text{ mm.}\\ d&=600 \text{ m.}\\ \hline Q&=3850 \end{aligned}$$

According to equation (8) we must multiply this value for Q by

$$k_2=\sqrt{\frac{18}{15}}=1{\cdot}095.$$

when we get $Q_2=1{\cdot}095 \,.\, 3850=4216$ cb. m.

(*d*) If we require the hourly carrying capacity, Q_3, of a pipe for a gas of any given density s_3 under any given pressure h_3, we must multiply the value Q taken from the table which is calculated for $h=15$ mm. and $s=0{\cdot}4$ by the coefficient k_1 (see equation 4) to compensate for the difference in the density of the gas from $0{\cdot}4$, and by

the coefficient k_2 (see equation 7) to compensate for the difference in the pressure of the gas from 15 mm.

We have also $Q_3 = k_1 k_2 Q = k_3 Q$, where

$$k_3 = k_1 k_2 = \sqrt{\frac{0\cdot4}{d_1}\,\frac{h_2}{15}}, \tag{9}$$

and

$$Q_3 = k_3 Q = \sqrt{\frac{0\cdot4}{15}\,\frac{h_2}{d_1}}\,.\,Q = 0\cdot164\sqrt{\frac{h_2}{d_1}}\,Q. \tag{10}$$

Example 6.—Given the data of Example 1, except that $d = 0\cdot46$ and $h = 20$ mm., find Q.

From Table IX. we find $Q = 3850$ (as in Example 1).

From Table X. we find the square root of $d_1 = \sqrt{0\cdot46} = 0\cdot6782$.

From Table XI. we find the square root of $h_2 = \sqrt{20} = 4\cdot4721$, therefore

$$\sqrt{\frac{h_2}{d_1}} = \frac{4\cdot4721}{0\cdot6782} = 6\cdot594$$

$$k_3 = 0\cdot164 \times 6\cdot594 = 1\cdot081$$

$$Q_3 = 1\cdot081 \times 3850$$

$$= 4163 \text{ cb. m.}$$

§ 13. DETERMINATION OF THE DENSITY OF A GAS.

This is found by accurately weighing a known volume of the gas, taking into account the temperature, barometric pressure, and relative humidity of the air displaced.

(1) **Ordinary method.**—The apparatus consists of a glass sphere of about 10 litres capacity with two stop-cocks situated at opposite sides of the sphere, a good air pump, and a very sensitive balance. The weighing room must be provided with a barometer and thermometers to read the temperatures both of the air and the gas.

Method of using the apparatus.—Both stop-cocks are first opened, whereby the glass sphere is filled with air at the same barometric pressure and temperature as the external air. The sphere is weighed in this condition and the weight G noted.

The glass sphere is now connected by means of one of the stop-cocks to the pump, the other stop-cock is closed, and the vessel is exhausted as far as possible. After the second stop-cock has been closed the pump is disconnected and the vessel again weighed. If the sphere now weighs say 13 gm. less than before, this difference represents the weight of the air removed.

The sphere is now connected by a glass tube leading to the

source of supply of the gas, and the whole is filled with gas. As soon as full the connections are removed and the sphere is again weighed. If the weight of the sphere filled, say, with hydrogen gas were now 1·9 gm. heavier than when empty, then, 1·9 gm. represents the weight of hydrogen in the sphere.

In order to obtain the density of the gas with respect to air, it is only necessary to divide the weight of the gas by the weight of the air it displaces; the quotient represents the specific gravity of the gas with respect to air. In the hypothetical case taken this is $\frac{1 \cdot 9}{13} = 0 \cdot 146$.

(2) **Dr Letheby's method.**—Dr Letheby's apparatus consists of a similar glass sphere *a*, (see fig. 6), of about 16 to 20 cm. diameter, to which are attached two stop-cocks, *b*, *b*. A glass tube, *f*, about 1·5 cm. in diameter and 20 cm. long is connected to one of these taps, and has a burner, *d*, fixed at the other end. A thermometer, *c*, is placed inside the tube in order to determine the temperature of the gas. A piece of gas tubing is connected to the other stop-cock, and the gas is allowed to stream through the apparatus and burn at the upper end. The exact weight of air which the vessel will hold is inscribed on it. A counterpoise, exactly equal to the weight of the glass sphere when evacuated, is also provided. If we require to determine the density of the gas, we close the lower tap first, and immediately afterwards the upper one, closing the stop-cocks in this order so as to ensure that the pressure of the gas in the sphere is that of the external air, and not that of the gas in the tube, which would otherwise be the case. The sphere is now laid upon a balance, the counterpoise being laid in the other pan of the balance. A certain number of grains must now be placed in the pan containing the sphere in order to bring the beam into a horizontal position. If we find, for example, that a compensating weight of 15 grains is required, this is then the weight of the gas. If the weight of the air required to fill the sphere is 35 grains, then the density of the gas with respect to air is $\frac{15}{35} = 0 \cdot 429$.

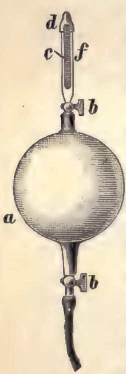

FIG. 6.

In such determinations the volume of the gas must be corrected for temperature and pressure; and the moisture present in all gases which comes into contact with water must be allowed for.

For these corrections, see §§ 5 and 9 of the section on "The Physical Properties of Gases."

(3) **Wright's method** (fig. 7) consists in weighing a light balloon of 1 cubic foot = 2·832 litres capacity to which a scale pan is attached. The method of experiment is as follows:—The balloon is first freed from all air by pressing it flat, and is then weighed along with the scale pan. It is now inflated with gas, corked up, and small weights are added to the pan until the balloon just floats in equilibrium. The number of grams required to bring this about is now added to the weight of the balloon, and the total lifting power of the gas thus obtained at the pressure and temperature of the weighing room.

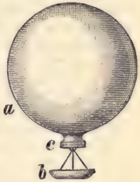

FIG. 7.

Since the lifting power is given by the formula

$$T = Va(1-d) - G,$$

the density (d) of the gas with respect to air is given by

$$d = 1 - \frac{T+G}{Va},$$

where

T = the lifting power measured in grams.
G = the weight of the balloon and scale pan in grams.
V = the volume of the balloon in litres.
a = the weight of one litre of air in the weighing room, which can be calculated from the formula

$$a = \frac{1{\cdot}293b}{(1+\alpha t)760}$$

where b is the barometric pressure, t the temperature in °C., $\alpha = 0{\cdot}003665$ the coefficient of expansion of air.

Example.—To find the density of the gas, given the following particulars:—

Contents of the balloon, $V = 100$ litres.

The combined weight of the balloon and scale pan $G = 56$ gm.
Its lifting power $T = 18$ gm.
The temperature of the room $t = 15°$ C.
The barometric pressure = 740 mm.
From these data we find

$$a = \frac{1{\cdot}293 \times 740}{(1 + 0{\cdot}003665 \times 15) \times 760} = 1{\cdot}193\ \frac{\text{grams}}{\text{litre}};$$

$$d = 1 - \frac{T+G}{Va} = 1 - \frac{68}{100 \times 1{\cdot}193} = 0{\cdot}43.$$

(4) **Giffard's method** is similar to the one described above, except that in Giffard's arrangement the weighing is automatic, the balloon carrying a chain consisting of loops of equal known weights, which, when full, it partially raises from the ground. By simply counting the number of loops raised by the balloon and adding to their weight that of the balloon itself, we get the lifting power of the gas.

(5) **Lux's gas balance** depends on Archimedes' principle. It consists of a balance beam to one end of which is attached a glass sphere, while the other end carries a pointer together with a counterpoise weight. The beam vibrates between two concave stop-cocks in a sort of fork, which is screwed down to the foot-plate. The one stop-cock communicates by means of a water or mercury connection with the interior of the sphere, by means of which the vessel can be filled with gas. The second is

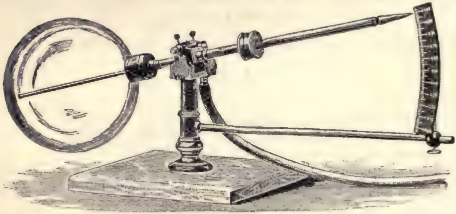

FIG. 8.—Lux's gas balance.

similarly in connection with a tube leading into the sphere and serves as an exit for the gas.

The pointed counterpoise moves along a scale attached to a suitable arm.

Method of using the apparatus.—When the sphere is filled with air the counterpoise is adjusted so that the pointer reads 1. The gas to be investigated is now led into the sphere by means of gas-tight tubes; this causes the sphere to move upwards for gases lighter than air, and the pointer points to a number on the scale less than 1. This number gives directly the density of the gas with respect to air.

(6) **Bunsen's apparatus** depends on the principle that the velocity (v) of diffusion of a gas through a small orifice at a constant temperature varies as the square root of the density of the gas, and is directly proportional to the difference of pressure between the two sides of the orifice.

We have, in fact,

$$v=\sqrt{2g\frac{p}{s}}\,.$$

By observations on the times, t_1, t_2, taken for equal quantities of two gases under equal pressures to flow through a small orifice, we obtain their relative densities, s_1, s_2. From the above formula we shall have

$$s_1 : s_2 = t_1^2 : t_2^2,$$

whence

$$s_2=\frac{s_1 t_2^2}{t_1^2}\,.$$

CHAPTER II.

THE PHYSICS OF THE ATMOSPHERE.

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§ 1. CONSTITUENTS AND GENERAL PHYSICAL PROPERTIES OF THE ATMOSPHERE.

(*a*) **Constituents.** — The atmosphere of the earth, reaching certainly to a height of more than 300 km., is a mixture of 78 parts by volume of nitrogen, 21 of oxygen, and 1 of argon. Besides these there are present varying quantities of carbon dioxide, about 0·03 per cent.; of ammonia, about 0·000003 per cent.; and of sundry other gases, but above all of aqueous vapour, up to 3 per cent.; and, lastly, solid particles of organic and inorganic matter. These latter are present in an extremely finely subdivided state everywhere up to a certain height, generally in enormous numbers. Aitken found as many as 210,000 such dust particles per cubic cm. in the air of Paris, 140,000 in London, 470,000 in Glasgow, 104,000 on the Eiffel Tower, and 14,400 on the summit of Ben Nevis (where the height is such that the number rapidly approaches zero as we rise further). The number is very variable from place to place, and still more variable with the time. No observations on the number present in the free atmosphere have as yet been made.

(*b*) **Physical properties.**—Air is one of the so-called permanent gases, and possesses, therefore, all the physical properties of these gases. We will add a few further particulars to those given in Chapter I., which dealt with the relations between pressure, volume, temperature, and density, and with specific heats. We will write the fundamental characteristic equation for air (from Charles and Boyle's Laws) in the form

$$\frac{p\,.\,v}{T} = \frac{p_0 v_0}{T_0} = 29{\cdot}27\,. \tag{1}$$

The conductivity for heat of air is very small, only about

$\frac{1}{3500}$ that of iron, and is, for the physics of the atmosphere, negligible. The convection of heat arising from the upward movement of warmer, and therefore lighter, air, the downward movement of cooler, and therefore heavier, air, and the movements in a horizontal direction (the wind), plays, on the contrary, a most important rôle.

Air is, like all gases, more or less transparent. The opacity depends not only on impurities, such as dust particles and drops of water, but also, even if the air is perfectly pure, on the presence of masses of air of different temperatures, possessing, therefore, different densities and refractive indices. The behaviour of the atmosphere with respect to the sun's radiation is as follows:—The total radiation is diminished in its passage through the atmosphere by diffuse reflection, the different rays being diminished in intensity by different amounts, the violet rays most and the red rays least, the transparency decreasing with the wave-length of the rays. The intensity of the red light is diminished to 95 per cent. of its value above the atmosphere, orange to 87 per cent., blue to 74 per cent., and violet to 51 per cent. (mean, 83 per cent.) in passing through the atmosphere when the sun is at the zenith (Abney, "Transmission of Sunlight through the Atmosphere," *Phil. Trans.*). When the sun is nearly on the horizon, and the path to be traversed in the air is, therefore, longer, the red light is diminished to 75 per cent. of its value above the atmosphere, orange to 45, blue to 18, and violet to 2 per cent. (mean, 34 per cent.), these being the values when the sun is 10° above the horizon. The transmitted light becomes consequently richer and richer in red rays the lower the sun sinks (*cf.* red sun on horizon). As the sun rises, on the contrary, the blue rays increase more rapidly than the red.

Besides this general absorption, the atmosphere absorbs certain rays completely (absorption-lines and bands), very few in the visible part of the spectrum, but a great number in the infra-red, consisting of dark or heat rays of great wave-length (Langley). This selective absorption is increased by the presence of carbon dioxide and aqueous vapour in the atmosphere (*v.* Angström and Paschen, *Wied. Ann.*, vols. 39, 51, 52).

§ 2. THE SOURCES OF WARMTH IN THE ATMOSPHERE. SUN'S RADIATION.

The high temperature of the interior of the earth, which is propagated to the surface by conduction, is not quite without influence on the absolute temperature of the atmosphere (about 0·1° C.), but it has no influence at all on the alterations of temperature which take place, since it is constant in value. The

heat reaching the earth from the moon is scarcely measurable ($< \frac{1}{100,000}$ the sun's heat), since the temperature of its surface, even at full moon, is only 0° C. according to Langley; its variations are therefore quite negligible. The effect, also, of the combined radiation from the stars is immeasurably small. Lastly, the radiation of the heavens from outside the atmosphere can be at the highest only negative, since the temperature of space ought to lie near to the absolute zero of temperature,—273° C. The source of heat, to which all meteorological phenomena are ultimately to be traced, must finally be the heat of the sun.

The chief workers on the radiation of the sun have been Pouillet, Violle, Crova, and Langley. It is only in the most recent times that sufficiently accurate instruments (actinometers or pyrheliometers) have been devised for its absolute determination, the best being that of Angström-Chwolson (Chwolson, *Aktinometer. Untersuchungen zur Konstruktion eines Pyrheliometers*; and Angström, *Intensité de la radiation solaire*), though in balloon expeditions Arago-Davy's actinometer (a black bulb thermometer in a vacuum) has been up to now chiefly employed, but gives at best only relative values.

According to the measurements and calculations hitherto carried out, the sun, shining at perpendicular incidence on the earth's surface, the atmosphere being removed, would give 2·5 units (3 according to Langley) of heat per square centimetre per minute, which would melt in a year a thickness of ice of 45 (or 54, assuming Langley's estimate) metres. The temperature of the sun's surface works out from this to be 6000° to 8000° C. (Scheiner, *Strahlung und Temperatur der Sonne*, 1899). Nothing definite is known concerning the alteration of the temperature of the sun, or of the solar constant, with time. Owing to the varying altitude of the sun, and consequent alteration in the angle at which the sun's rays strike the earth's surface, the strength and duration of the illumination alters in a known manner according to the time and place.

The total yearly radiation decreases slowly at first as we go from equator to pole, then in our latitudes more rapidly and afterwards more slowly again, the total radiation at the pole being $\frac{5}{12}$ths of that at the equator.

The total daily radiation decreases at the equinoxes in a similar manner, *i.e.* seemingly regularly, as we proceed from the equator to the pole; at the summer solstice, on the contrary, when the illumination is zero from the south pole up to latitude 68°, it increases from this point up to the equator, and beyond up to latitude 43°, where it is a maximum, and beyond this becomes somewhat smaller up to 62° N. latitude, beyond which it again increases, reaching the principal maximum at the north pole, where it is about one-third greater than at the equator.

The opposite holds true, of course, at the winter solstice (Wiener, *Über der Stärke der Bestrahlung der Erde durch die Sonne*).

The amount and distribution of the sun's heat described above is completely altered by the presence of the atmosphere. At a few places the daily and yearly extent of the sun's radiation has been determined on bright days, these showing rapid and large variations.

The maxima were found to occur before midday, and to have their greatest value in April and May, their smallest in December. Taking the mean of all the daily values, July is found to have the greatest quantity of heat and December the least. We have not as yet got a precise knowledge of either the variation with time or place of the strength of the sun's radiation on the earth's surface, but calculations made by Angot (*Recherches théorétiques sur la distribution de la chaleur*) give us an approximate review of the distribution.

A portion of the total radiation of the sun, which would otherwise reach the earth's surface, gets lost by reflection at the upper surface of the atmosphere and at the surface of clouds, another part is absorbed by the atmosphere itself, and lastly part is diffused in the atmosphere (diffuse daylight). Some part of this last, however, ultimately finds its way to the earth's surface, since the diffuse heat radiation of the atmosphere forms about a tenth of the solar constant. In spite of this the radiation of heat away from the earth into the clear sky is greater both by day and by night than the radiation received (Homén, *Der tägliche Wärmeumsatz im Boden und die Wärmestrahlung zwischen Himmel und Erde*), and it is only when the heaven is clouded over that the reverse can occur.

The effective radiation of the sun brings about a corresponding heating of the earth's surface itself, which is diminished and delayed as it progresses downwards below the surface, and it is from the surface of the earth that the layer of air surrounding it receives its heat and is kept approximately at the temperature of the ground, so that the heat appears to be due to the warmth of the earth and not to the sun. The heating of the atmosphere is thus not caused simply by the direct influence of the sun's rays, but is modified by other factors; the temperature distribution in the lower strata of air, which is dealt with more fully in works on climatology, is therefore a very complex one.

Above all, the presence of aqueous vapour in the atmosphere and the variation in the nature of the earth's surface at different places (in both form and colour), in combination with the peculiarities shown by aqueous vapour and by water itself, cause the greatest irregularities. For the better understanding of

these influences we may compare, for example, the different actions of the quantities of heat given in the following table :—

To warm 1 cb. m. water 1° C.	requires	1000	units of heat (kilogram calories)
To warm 1 cb. m. earth 1° C.	,,	300–600	,,
To evaporate a layer of water 1 mm. in thickness per sq. m. of surface	,,	600	,,
To melt a layer of ice 1 mm. in thickness per sq. m. of surface	,,	79	,,
To warm the column of air resting on 1 sq. m. of the earth's surface 1° C.	,,	2454	,,
To warm 1 cb. m. of air (at 0° C. and at a constant pressure of 760 mm.) 1° C.	,,	0·307	,,

The heat which is being continuously radiated from the sun to the earth and its atmosphere might be expected to cause an increase in their temperatures. No such increase has, however, been detected even in the course of centuries, and at each corresponding period of the year the temperature is the same. From this it follows that the whole of the heat is lost again by radiation into space, except for the small fraction which is transformed into other forms of energy, *e.g.* coal which is produced from vegetation (von Bezold, *Der Wärmeaustausch an der Erdoberfläche und in der Atmosphäre*, 1892).

§ 3. PRESSURE OF ATMOSPHERE.

Every body, including the air itself, exists, under normal conditions, subject to a pressure equal to that of the column of air situated vertically above it, and supports this weight.

Since the pressure is exerted equally on all sides it is usually not detectable, but it is immediately noticed if the pressure on any side of the body is removed or diminished. For example, if we break open the lower end of an evacuated glass tube, closed at its upper end, under mercury, the mercury will forthwith rise in the tube until it exercises a pressure equal to that of the air pressing on the exposed surface of the mercury. The pressure of this column of mercury balances the pressure of the column of air above it. The height varies according to the time and place, but is normally = 76 cm. Taking into account the specific gravity of mercury (13·596), we find that this corresponds to a pressure of 10,333 kg. per square metre (normal atmospheric pressure). The pressure of

the air is generally expressed by the height of the corresponding column of mercury (usually in millimetres).

The above arrangement with a measuring scale is a type of mercury barometer, an instrument which is built in various forms according to the purpose for which it is to be used. In the aneroid barometer the alterations in the sag of the thin elastic cover of an evacuated metal box (Vidi) consequent upon the change in the external air pressure, or in the distance between the two ends of a highly evacuated spiral tube (Bourdon), is noted, magnified by a system of levers and made visible by a pointer attached to a suitable scale which must be calibrated by comparison with a mercury barometer.

Instruments which record continuously the pressure of the air are called barographs. In observatories, delicate barographs are required, recording the absolute pressure. For balloon work Richard's barograph is very convenient and satisfactory, but it must be compared from time to time with a mercury barometer. The movements of an evacuated metal box under the influences of changes in the pressure are magnified by levers, and are recorded by a pen on a strip of paper which revolves around a drum turned at a uniform rate by clockwork.

Since the boiling point of water varies in a definite manner with the pressure (being 100° C. at 760 mm. pressure, 95° at 634 mm.), an accurately graduated boiling-point thermometer can be used to determine the pressure; only, however, under certain special precautions for balloon work.

At sea level the variations of the atmospheric pressure at any one place never exceed 80 or 90 mm., the lowest pressure ever observed (reduced to sea level) being 688 mm. and the highest 809 mm., the greatest variation being therefore 121 mm. The mean of the pressure over a long period of time varies very little at different places (a few mm. perhaps) from 760 mm. It is relatively low at the equator (758), increases up to latitude 30° (763, or, on the sea, 765), and then decreases towards the poles, the decrease being very rapid in the southern hemisphere (the mean pressure being in latitude 60°, only 743), and very slow in the northern hemisphere (in latitude 60° being 759); in the latter case a further increase as we go towards the pole (up to 761) has been detected. These differences are, in spite of their small magnitude, of great importance (see below). Various regions on the earth show marked deviations from the mean pressure. The deviations become considerably greater at different periods of the year under the influence of the changing temperature, and are often completely altered in sense. The mean atmospheric pressure in mid-Atlantic, for example, sinks to 745 mm. in January, while at that time it is 775 mm. in the interior of Asia; on the other hand it is 760 mm. in July in mid-Atlantic, while it is

only 750 mm. in eastern Asia. Finally, the greatest irregularities appear when we consider the distribution of pressure for different phases of the weather. This is best seen when we connect points at the same pressure by lines (isobars). The distribution of these isobars forms the most important foundation for the science of the weather.

As we rise above sea level the column of air above us decreases, and the pressure consequently also decreases, still more rapidly, in fact, since the density also becomes smaller. The decrease in the pressure with the height follows the law of geometric progression, and can be expressed in the short and convenient, though not quite exact, formula,

$$h = 18400 \log \frac{b_0}{b} \tag{2}$$

h being the difference in height of the two stations in metres, b_0 the pressure at the lower station, and b that at the upper station. The exact relation, which has been verified time after time by actual measurement, takes into account the temperature, humidity, and alteration in gravity over the whole height h.

It has the complicated form,

$$h = 18400 \log \frac{b_0}{b} (1 + 0{\cdot}0037\, t) \left\{ 1 + \frac{0{\cdot}377}{2} \left(\frac{e_0}{b_0} + \frac{e}{b} \right) \right\} (1 + 0{\cdot}0026 \cos 2\phi)\left(1 + 2\frac{\mathrm{H}}{r}\right), \tag{3}$$

where h, b_0, and b have the same meanings as before, t is the mean temperature of the column of air, e the pressure of aqueous vapour, ϕ the mean geographical latitude, H the mean height above sea level, and r the radius of the earth (about 6370 km.).

This formula may be much simplified if rather less accuracy is sought for, and a very convenient form, suitable for most purposes, given by Köppen, is,

$$h = 18432 + 72\left(t + \frac{45 - \phi}{52}\right) \log \frac{b_0}{b}\,.$$

(If $t < 0°$ the number 72 must be replaced by 69).

The readiest and most convenient way of obtaining the height, or difference in heights, is by the use of tables based on the barometric height formula. The best tables are W. Jordon's "Barometrische Höhentafeln," especially those calculated "für Tiefland und grosse Höhen" (1896); the barohypsometrical tables in the "Tables météorologiques internationales"; and the "Smithsonian Meteorological Tables." For the rapid calculation of approximate values the barometric height tables (Table XIII.), abbreviated from Jordon's tables, may be used.

These give the heights for pressures of 770–250 mm. for every 10 to 10 mm., and for every 10° to 10° difference in temperature (useful for manned balloon work), and for every 50 to 50 mm. pressure below 250 mm. (useful for registering balloon work), all calculated for an initial pressure of 762 mm.

§ 4. TEMPERATURE OF THE AIR.

The temperature of the air at any given point is the product of several factors which have already been briefly mentioned above. It is measured by instruments in which the expansion of a gas (air-thermometer), or of a liquid (mercury or alcohol thermometer) caused by heat, gives the degree of warmth according to a definite scale. Mercury is most commonly used, but below – 38·5° C., at which temperature mercury freezes, alcohol must be used. Three scales are in general use: the Centigrade scale (C.), the Réaumur (R.), and the Fahrenheit (F.) scales. The readings on the various scales may be compared with one another by means of the formula:

$$(4) \qquad C^\circ = \frac{5}{4}R^\circ = \frac{5}{9}(F^\circ - 32).$$

where C°, F°, R° represent the readings in degrees on the particular scale. In scientific publications the Centigrade scale only is employed (English publications excepted), in which the freezing point of water is taken as zero, and its boiling-point, under normal atmospheric pressure, as 100°.

Even a good instrument, when brought into contact with the air, does not give directly the true temperature of the air, since, on account of the transparency of air to heat radiation of various kinds, and on account of the conductivity of the air, it can be influenced by external sources of heat.

At meteorological stations in Great Britain the Stevenson screen, made of wood, double louvred, erected on four supports so that the thermometers stand about four feet (1·3 m.) above the ground, is used as a protection against radiation. On the Continent zinc-plate or canvas huts are frequently employed for the same purpose.

Assmann's ventilated thermometer really overcomes the difficulties best of all, especially in balloon work, where there is no movement of the air, and the radiation of the sun is enormously powerful.

For obtaining a continuous record of the temperature, thermographs are used. The simplest and handiest form in use is Richard's thermograph, which consists of a thin bent double strip filled with alcohol; its radius of curvature is altered by any change in the temperature, the alterations being suitably exaggerated by levers as in the case of the barograph, and

recorded on paper strips on a revolving drum. The instrument must be calibrated from time to time by comparison with a standard thermometer. From frequent, if possible hourly (but usually three per day), determinations of the temperature the daily mean of the temperature is calculated, and from these the mean monthly and the mean yearly temperatures are determined.

This mean varies from year to year about a mean value—the normal value—which is given by observations extending over many years, and is useful for climatic comparisons.

The normal yearly temperature is highest in the tropics up to latitude 30°, after which it decreases somewhat irregularly up to the North Pole. The irregularities are due to the influence of the continents and oceans, and of land and sea currents. It decreases fairly regularly up to the South Pole, and has a minimum value at about $-20°$ C. in polar North America. The mean normal temperature for the whole earth may be taken as 15° C. In Germany it varies from 10° in the south-west to 6° in the north-east.

The alteration of the seasons causes only small alterations in the temperature along the equator; in other latitudes large changes result from the changes of summer to winter and winter to summer. The changes are the greatest on the continents, and are very small in mid-ocean. The normal temperature for January is lowest ($-48°$ C.) in north-east Siberia, and highest ($+32°$ C.) in the interior of Australia; the normal temperature for July is lowest on the antarctic continent and highest ($+34°$) in the Sahara. In the plains of Germany January is coldest ($-5°$) in the north-east interior part of the country, and mildest ($+2°$) in the north-west; July is coolest ($+16°$) on the coast of the North Sea, and warmest ($+20°$) in the south-west.

The highest atmospheric temperature recorded was observed in the interior of Arabia ($+57°$ C.), and the lowest temperature in Werchojansk, Siberia ($-68°$ C.). Temperatures in the neighbourhood of 40° and lower than $-35°$ have been actually observed in Germany.

The temperature distribution is most clearly seen when places having the same temperature are joined by lines (isotherms). The influence of sea and continent, and of sea and land currents, on the temperature distribution is seen most clearly when places for which the deviation from the mean temperature for the corresponding latitude is the same are joined up by lines (isabnormals).

The temperature of the air shows much more rapid alterations in a vertical than in a horizontal sense. We have already seen that the sun's radiation warms the air itself less than the ground, which shares its heat with the lower strata of air; these, in consequence of their lighter weight, stream upwards in the atmosphere, enter a region where the pressure is lower,

expand, and therefore cool in the course of the ascent (*cf.* Chapter I. § 10). This is the cause of the diminution in the temperature with the height. If we neglect the influence of the surrounding atmosphere, the rate of cooling of a mass of dry air in ascending would be almost exactly 1° C. per 100 m., or of damp air somewhat less, and depending to a certain degree on the pressure and temperature, but on an average being perhaps 0·5° C. per 100 m. In nature, however, this state of indifferent equilibrium is considerably altered by other causes. The lower strata of air may perhaps become rapidly heated by strong sunshine in very calm weather, so that the diminution of temperature with height becomes greater than 1° per 100 m. or even 3° per 100 m. (unstable equilibrium), or, perhaps, in consequence of a calm clear night, the ground may become intensely cold through loss of heat by radiation, so that the temperature actually increases with the height (temperature inversion). Condensation occurring, this increase of temperature with height is checked, and clouds are formed which become heated on their upper edge in the daytime and strongly cooled in the night; soon perhaps air currents of foreign origin appear with different temperatures in their different strata. In addition to these there are the influence of the different shapes of the earth's surface (peaks, declivities, or valleys), the disposition of land, the general configuration of the ground, and the character of the surface (land or sea). These and other causes prevent any definite general law being found for the decrease in the temperature with the height. In fact this decrease will have widely different values in hot and cold weather, by day and by night, in winter and in summer, and in places differently situated.

On the whole, observations on mountain stations show that the decrease per 100 m. is fairly regularly 0·5 to 0·6° C. For Europe in the different months the following average values may be taken as approximately correct:—

Jan.	Feb.	Mar.	Apr.	May.	June.
0·39	0·47	0·59	0·66	0·68	0·66° C.
July.	Aug.	Sept.	Oct.	Nov.	Dec.
0·64	0·62	0·58	0·52	0·43	0·37° C.

and for the year 0·55° C.

In deducing the temperature gradient from observations taken on mountain stations it is necessary to remember that the situation of the station plays an important part in influencing its temperature, which may be very different to the temperature at the same altitude in the free atmosphere. Other values altogether have been found for the temperature gradient from balloon observations. For many years the gradients deduced

from observations obtained in Glaisher's ascents were accepted as correct, and although modern critics have shown Glaisher's results to be far from correct, we will quote them as being of historic interest.

Mean height in metres.	Decrease per 100 m. in	
	Summer.	Spring and Autumn.
	° C.	° C.
500	0·88	0·71
1475	0·60	0·50
2450	0·49	0·43
3450	0·42	0·43
4425	0·37	0·44
5400	0·36	0·34
6550	0·21	0·18
8350	0·17	...

We will give, for comparison with these figures, those obtained as a result of modern ascents, more especially those obtained in the Berlin ascents (Assmann and Berson, *Wissenschaftliche Luftfahrten*, 1900), and those obtained by Teisserenc de Bort from the records of three *ballons sondes* sent up from Trappes.

Berson.			Teisserenc de Bort.	
Height in km.	Mean temperature.	Decrease per 100 m.	Mean temperature.	Decrease per 100 m.
	° C	° C.	° C.	° C.
0	10·1	0·50	9	0·4
1	5·4	0·50	5	0·5
2	0·5	0·54	0	0·4
3	− 5·0	0·53	− 4	0·5
4	− 10·3	0·64	− 9	0·7
5	− 16·6	0·69	− 16	0·5
6	− 24·2	0·66	− 21	0·8
7	− 29·4	0·72	− 29	0·9
8	− 38·3	0·90	− 38	0·6
9	− 46·4	...	− 44	0·7
10	...	...	− 51	...
Mean.	...	0·63	...	0·6

The greatest height at which the thermometer has been directly read is 10,250 m. (Berson and Süring on the 31st July 1901), where the temperature observed was $-40°$ C.; the greatest height hitherto reached by a registering balloon is roughly about 25 km., and the lowest recorded temperature $-70°$ C.; the lowest temperature observed in a manned balloon was, however, $-48°$ C. (Berson, 4th December 1894, at a height of 9150 m., and Süring, 24th March 1899, at a height of 7750 m.).

While the numbers obtained by Glaisher, on account of the want of ventilation of his thermometers, show a diminution in the rate of temperature decrease with height, the values obtained by Berson and Teisserenc de Bort show that the reverse is true and that the theoretical adiabatic value for the temperature gradient for dry air is more nearly approached at high altitudes. Although the two examples given of the temperature distribution differ somewhat, this can be accounted for firstly by the small number of ascents from which the means are calculated, and secondly by the want of accuracy in the thermographs; they show the same general tendency, viz., a gradient slightly below the normal in the lower strata in consequence of the constantly occurring temperature inversion; followed by a more normal diminution in temperature at greater heights with occasional breaks in the rate of diminution owing to condensation (clouds), and a gradient, approaching the adiabatic gradient for dry air, at still greater altitudes.

In the different seasons of the year the values of the temperature naturally differ in the various layers of air, and likewise the temperature gradient. The Berlin ascents give the following results on this point:—

Height, km.	Mean temperature of the air in			
	Winter.	Spring.	Summer.	Autumn.
	° C.	° C.	° C.	° C.
0	0·3	8·7	18·4	9·3
1	− 0·6	2·5	11·0	5·4
2	− 5·1	− 2·1	5·3	1·6
3	−10·8	− 8·6	0·9	−2·6
4	−14·6	−14·5	− 5·0	−7·1

Height. between	Mean decrease per 100 m.			
	° C.	° C.	° C.	° C.
0 − 1 km.	0·0	0·5	0·7	0·5
1 − 2 ,,	0·4	0·5	0·6	0·4
2 − 3 ,,	0·6	0·6	0·5	0·5
3 − 4 ,,	0·5	0·5	0·6	0·5
4 − 5 ,,	0·7		0·6	
5 − 6 ,,	0·7		0·7	

According to Teisserenc de Bort the mean decrease at different seasons is as follows :—

	Winter.	Spring.	Summer.	Autumn.
between 0 and 5 km.	0·42	0·46	0·48	0·40° C.
5 and 10 km.	0·65	0·66	0·72	0·70° C.

(*Note.*—The smaller values obtained by Teisserenc de Bort can be accounted for by the fact that his ascents were mostly made by night.)

By a more exact study of the figures we learn that there is a delay in the seasons with the height and a diminution in the yearly amplitude of temperature. Although up to the present time it has been usual to assume that the decrease of the amplitude of the yearly variation with height was great, recent investigations have shown that the decrease is not very considerable.

At a height of	The yearly amplitude is
0 km.	16° C.
3 ,,	13
5 ,,	13
10 ,,	9

The aperiodic alterations of temperature also are found to be unexpectedly large even at a height of 10 km. and more.

The daily temperature period, on the other hand, is a phenomenon confined to the lower strata of the atmosphere, and diminishes rapidly with the height. Observations taken on free ascents are too few and far between to make out those relationships accurately. For this purpose captive balloons and kite ascents give the most fruitful results. They have already shown the great frequency with which temperature inversions occur in the lower regions of the atmosphere, and, on the other hand, the frequent occurrence of a state of unstable equilibrium (a decrease in temperature of more than 1° C. per 100 m.). At the present time, however, observations taken over many years on high towers are taken as the basis of theoretical investigations on this subject.

On the Eiffel Tower the mean fall in temperature per 100 m. was found to be :—

	In Winter.	Spring.	Summer.	Autumn.	Mean for year.
Up to a height of 123 m.	– 0·12	0·19	0·23	– 0·26	0·01° C.
Between 123 and 302 m.	0·27	0·46	0·53	0·34	0·40° C.

The mean yearly temperature is therefore the same at a height of 123 m. as on the ground beneath, being warmer throughout the autumn and winter and cooler in summer, though the temperature gradient is very small. The decrease up to a height of 302 m. is also below the normal. These phenomena are all connected with the strength and duration of the temperature inversion.

On an average this lasts at a height of:

123 m.	nearly 14 hours per day,	and the temp. is an average		0·9° C.
197	,, 13	,,	,,	0·8° C.
302	,, 10	,,	,,	0·6° C.

above that on the surface. In the hours during which the greatest radiation into space occurs the temperature increases on an average 2° C. up to a height of 123 m. and a little more up to 302 m. The most surprising feature is the intensity of the phenomenon in autumn and the only slightly smaller intensity in spring, while in winter it is of interest more from its long duration (more than sixteen hours per day at a height of 123 m.).

We can deduce that first at heights over 500 m. or 1000 m., according to the season, the air possesses at every hour of the day a temperature lower than that of the air next the ground. In occasional cases the inversion can extend much higher, and last days or even weeks, and attain a very considerable value. This is proved by observations on mountains, and also in the free atmosphere. For example, on 12th January 1894 the temperature rose 16° C. in 700 m. above Berlin, and the air had the same temperature as on the earth's surface only when a height of 4000 m. had been reached, and on 10th January 1901 the temperature over Przemisl rose fully 25° C. in 1100 m.

While the normal temperature inversion in the lower air strata is principally a night phenomenon, the temperature gradient in the daytime, on the contrary, is generally very steep. Between 9 a.m. and 3 p.m. in the summer a state of unstable equilibrium is common, and at mid-day the temperature decrease in 100 m. is on the average 2° C. greater than the normal amount. In isolated cases observed in free balloons, a state of unstable equilibrium has been found to exist up to a height of 2500 m. above the earth's surface.

On these grounds the decrease in the daily amplitude is influenced greatly by the height. The following numbers were deduced from observations taken on the Eiffel Tower:—

Height.	Mean daily amplitude		
m.	In the year.	In April.	In December.
2	7·2°C.	10·2° C.	3·5° C.
113	5·1	7·2	2·3
197	4·4	6·4	2·0
302	3·6	5·1	1·4

If we carry out the calculations for still greater heights we find that at a height of 900 m. the daily amplitude is reduced to 0·7° C. and at 1700 m. to 0·1° C., so that above 2 km. in the free atmosphere no daily range of temperature can be detected.

§ 5. HUMIDITY OF THE AIR.

The aqueous vapour present in the air plays an important part in the economics of the atmosphere, since the frequent changes in its condition of aggregation (vapour, water, ice)—quite independent of its absorptive and reflective action—influence to an enormous degree its heat relationships and consequently its movements. Heat is needed to cause evaporation (latent heat), 1 kg. water requiring at 0° C. 606 and at 100° C. 536 calories. Seventy-nine calories are necessary for the melting of 1 kg. ice. In the reverse processes (condensation and freezing) the same quantities of heat are set free. The density of aqueous vapour (*cf.* also §§ 7–9 in Chapter I., *A*) is 0·623 (at 0° C. and 760 mm. pressure) of that of air, so that damp air is lighter than dry air.

The aqueous vapour present in the air is expressed either by the pressure in mm. mercury which would hold it in equilibrium (vapour pressure $= e$), or by the actual weight of vapour present in 1 cb. m. air (absolute humidity $= f$). The vapour pressure in mm. and the absolute humidity in gm. have about the same numerical value and are frequently confused; the exact relationship between the two is given by the equation

$$(5) \qquad f = 1{\cdot}06 \frac{e}{1 + 0{\cdot}00367\,t}.$$

Air can, at any given temperature, only hold a certain definite quantity of aqueous vapour, and as soon as it holds this quantity, is said to have reached the point of saturation. As soon as this has been exceeded, or the temperature sinks below the dew-point, condensation begins. The pressure which this maximum

quantity of vapour exerts is called the maximum tension of aqueous vapour at the corresponding temperature. The values of the maximum tensions in mm. at each degree Centigrade are given in Table VIII. of the Appendix.

The ratio of aqueous vapour present in the air to the maximum quantity which the air could contain at the particular temperature, expressed as a percentage, is termed the "relative humidity."

The amount of aqueous vapour can also be expressed advantageously, especially in investigations on the vertical distribution of the vapour, by the quantity of aqueous vapour present in 1 kg. of the moist air—the specific humidity, the value of which is given by

$$(6) \qquad 0{\cdot}623\,\frac{e}{b-0{\cdot}377\,e},$$

or by the quantity of aqueous vapour present per kg. dry air (mixture ratio),

$$0{\cdot}623\,\frac{e}{b-e}.$$

The presence of moisture throughout the whole atmosphere is proved by the spectroscope, which shows certain absorption lines in the sun's spectra.

The most exact determination of the moisture present is attained by absorbing the moisture from a weighed quantity of air, which is weighed again afterwards. Another method consists in determining the dew-point by cooling the air (condensation hygrometer), while a third depends on the hygroscopic properties of certain substances (hair hygrometer, Richards' hygrograph with continuous records). Usually, however, a psychrometer is used: a thermometer, the bulb of which is covered with moistened linen; this reads a lower temperature than one having its bulb uncovered on account of evaporation of the moisture, and the drier the air the greater the evaporation and the greater the difference in temperature between the wet and dry bulb thermometers. If t is the temperature of the dry bulb thermometer, t' that of the wet bulb thermometer, and e' the maximum tension of the aqueous vapour (or ice vapour if ice is present on the wet bulb thermometer) at the temperature t', then e, the pressure of vapour actually present, is given by

$$(7) \qquad e=e'-\frac{0{\cdot}48(t-t')b}{610-t'},$$

where b is the atmospheric pressure in mm., and where, if $t'<0^\circ$, the number 610 must be replaced by 689. From this it is easy to calculate the relative humidity. The psychrometrical tables

of Wild-Jelinek, published by Hann, are the most complete and correct in use. For the ventilated psychrometer, which is also of the greatest service for this purpose, the following formula has been found to hold:—

$$(8) \qquad e = e' - 0{\cdot}5(t - t') \cdot \frac{b}{755}.$$

The distribution of aqueous vapour in the lower strata of the atmosphere is closely related to the distribution of temperature, increasing in amount from the equator to the poles, the general mean values lying between about 20 mm. and 2 mm. (in Berlin 7 mm.), the greatest mean monthly variation being 25 mm. (tropics), and the smallest <1 mm. (Siberia), being in Berlin 11 mm. and 4 mm. resp. The mean relative humidity decreases from 80 per cent. at the equator to 70 per cent. about latitude 35°, whence it increases as we approach the north pole to above 80 per cent.; in Berlin the mean yearly value is 75 per cent., being in May 65 and in December 85 per cent. The values are naturally greater over the sea and least on dry land. The driest deserts have always, on an average, an absolute humidity of 5 to 10 mm. and a relative humidity of from 20 to 40 per cent.

Hann has derived the following formula for the vertical decrease in the pressure of aqueous vapour from numerous observations on mountain stations:—

$$(9) \qquad e_h = e_0 \, 10^{-\frac{h}{6{\cdot}3}},$$

where h is the height in kilometres, e_h is the vapour tension at the upper station, and e_0 that at the lower station.

In the free atmosphere, however, Süring finds from balloon observations that the following formula is better:—

$$e_h = e_0 \, 10^{-h\left(1+\frac{h}{20}\right)},$$

where h is the height in kilometres.

According to the latter formula there remains

at a height of	1	2	3	4	5	6	7	8	km.
on an average still	68	41	26	17	11	5	3	1	per cent.

of the moisture present at the earth's surface.

In any case the decrease is very rapid, and above a height of 8 km. we have almost perfect dryness. In summer, in our latitudes, the whole of the water vapour present in the atmosphere may be taken as equivalent to a rainfall of about 25 mm.

The relative humidity alters much more irregularly with the height; according to balloon observations generally decreasing at first, afterwards increasing in cloud regions, only to decrease again as we rise above these.

§ 6. CLOUDS AND RAIN.

If the temperature of a mass of air falls gradually to below the dew-point, fog begins to be formed, or clouds at some height. It has been shown that the presence of dust particles is necessary for this to occur, otherwise the air becomes supersaturated with moisture, which beyond a certain limit leads to condensation. The cooling and consequent cloud formation can take place:

(1) By contact with the cold ground (mist, fog).

(2) Through the mixing of warm and damp masses of air (stratus clouds); if the horizontal layers coming into contact have different velocities and directions, billowy clouds (alto-cumulus = fleecy clouds, cirro-cumulus = feathery heaped clouds) are formed (Helmholtz, "Über atmosphärische Bewegungen und zur Theorie von Wind und Wellen," *Sitz.-Ber. d. Akad. d. Wissenschaften zu Berlin*, 1888 and 1889).

(3) By the expansion of a mass of warm moist air in the course of its ascent, this being the most frequent source of cloud formation (cumulus = wool-pack clouds, cumulo-stratus = piled-up masses of clouds, nimbus = rain clouds). v. Bezold discusses, in his *Zur Thermodynamik der Atmosphäre*, the physical processes which occur during the ascent of masses of moist air in their most general form. All considerations and calculations in connection with this subject are much simplified by Neuhoff's tables in his article on "Adiabatische Zustandsänderungen feuchter Luft" (*Abhandlung des Preussichen meteoroglischen Instituts*, 1900). The approximate height at which cloud is formed owing to this cause is given by the equation

$$H = 125(t - t'),$$

where t and t' are respectively the temperatures of the air and the dew-point.

Most of the principal forms of clouds, first classified by Luke Howard, *On the Modifications of Clouds*, are explained by the conditions of their formation given above, but neither the experimental researches nor the nomenclature can be considered complete, while the formation of the cirrus (= feathery) clouds, and the cirro-stratus (= feathery sheets of) clouds, remains still an unsolved problem, even though they are known to be constituted of ice crystals.

The classifications of the clouds made by Abercromby and Hildebrandsson have at present most supporters (The *Atlas international des nuages*, 1896, contains pictures of the clouds with their definitions). Before going further into the subject, it will be convenient to give a table showing the average heights,

roughly estimated in metres, of the various forms of clouds, along with their average velocities, obtained from observations by von Ekholm and Hagström, and by Clayton, and from the first year's results (1896–7) of the International Observations on Clouds. The heights of the cloud formations are given in the following table:—

		Height in metres.	Velocity in metres / second
Highest clouds	Cirrus	7000–11000	30–40
	Cirro-stratus	7000–9000	30
	Cirro-cumulus	7500	15–35
Moderately high clouds	Alto-cumulus	3000–6000	15
	Alto-stratus	4000–6000	20
Low clouds	Cumulo-stratus	1500–2500	10
	Nimbus	500–1500	...
Clouds in ascending columns of air	Cumulus	1500	10
	Cumulo-nimbus (thunder clouds)	1500–4000	15
Ground fog	Stratus	500	7

The values as observed at different times show considerable variations; cirrus cloud can certainly appear at a height of 15 km., and its upper surface may even extend to a height of 20 km., while the clouds in ascending columns of air may extend to a height of 10 km. The mean height of the clouds has also a daily and yearly period in the sense that the height is greater when the temperature is higher.

The depth of the clouds varies from a few metres up to 6 km., and even more for thunder clouds. The velocity also varies appreciably according to the time and place; the greatest velocity observed is for the cirrus clouds, viz., 100 metres per second.

It may be noticed at this stage that the so-called luminous night clouds are, according to Jesse, about 80 km. high, and have mostly velocities much greater than 100 metres per sec., and appear to come out of the east.

It appears, as Vettin first suggested, that there are heights between which cloud formations are much more common than in the remaining regions of the atmosphere. One maximum

lies in the cumulus region (2 km.), another in the cirrus region (8 to 10 km.). Süring has found that certain heights are peculiar, not only in connection with cloud formations, but also from the fact that all meteorological elements appear to undergo some change there—the various heights being 500, 2000, 4300, 6500, 8300, and 9900 metres.

The directions, velocities, and heights of clouds are determined either by cloud mirrors, nephoscopes, or most accurately by photogrammetrical means. For a complete account of cloud measurement, see Hildebrandsson and Hagström, *Des principales méthodes, pour observer et mesurer les nuages*, 1893.

For a consideration of the different relations the sum of the cloudiness of the sky is an important factor; this is estimated according to a scale of 10, or more correctly 11, degrees (0 = perfectly clear sky, 10 = quite overcast). The average cloudiness depends naturally on the opportunities for mist and cloud formation. Along the equator it is rather large (about 6), it diminishes to about 4 in latitude 30°, and afterwards increases as the poles are approached to over 7; it is smallest in the deserts (only about 2); in Berlin it is 6½.

A modification of this method of estimating the cloudiness, at least in the daytime, is the determination of the duration of sunshine by sunshine recorders. Campbell-Stokes' is that most generally employed. According to its records the average number of hours of bright sunshine received per day in different countries is as follows:—in Scotland, 3; England, 4; Germany, 5; France, 5 to 6; Austria, 5 to 7; and in Spain, 7 to 8.

According to Assmann the condensation nuclei are small spheres, whose diameters may be as small as 0·006 mm. Taken as a whole they form mist and clouds. The appearance of floating which a cloud possesses is due to the fact that these small drops can, in consequence of the resistance of the air, fall only very slowly—a small sphere 0·01 mm. in diameter not being able to fall at a more rapid rate than 1 cm. per sec.—in combination with the fact that there is a continuous formation of new droplets. By combining with one another, and descending, the small droplets increase in size to larger and larger drops, and, if they do not pass through a dry region and evaporate, ultimately fall as rain. The diameter of a drop of rain never exceeds 7 mm. When the temperature falls below 0° C. the drops are easily supercooled, and freeze only on coming into contact with foreign substances. Usually, however, the condensed vapour falls from the air as hexagonal snow crystals, which, combining with one another, form flakes of snow (see Hellmann, *Schneekrystalle*, 1893). In stormy weather they freeze together to form sleet.

Hailstones have a more solid structure, and their mode of

formation is, in spite of numerous hypotheses, still an open question. In extreme cold a countless number of ice crystals are formed by condensation around snow crystals, which also form the elements of cirrus clouds. Occasionally rain-drops and snow-flakes contain large quantities of atmospheric dust of mineral or vegetable origin (spray, red rain, sulphur rain). With these we have now enumerated the most important forms in which moisture is precipitated from the atmosphere.

Condensation taking place on the strongly cooled surface of the earth causes dew, or, when the temperature is below zero, hoar frost. Rime is a deposit of supercooled mist-drops carried by the wind, which, on reaching the ground, freeze. Ice is produced when supercooled rain-drops fall on the ground, and when, after a cold period, moist air comes into contact with objects still below freezing point.

The precipitation of moisture on the earth's surface is measured by the rain gauge; the quantity of water collected in the gauge giving the depth of rainfall: snow, of course, must be first melted. Continuous automatic records of the rainfall are made by suitable recording rain-gauges (the simplest and best being that of Hellmann-Fuess). The horizontal distribution of the precipitation is very irregular, and depends not only on the atmospheric conditions, but also on the configuration of the land. The mean total yearly rainfall may reach several metres (in Cherapunji, 12 m.), in Europe as much as 4 metres, in Germany at most 2 metres, and may be as low as a few cm. in deserts—in Germany as low as 0·5 m. The greatest rainfall recorded anywhere in one day is more than 1 m.; in temperate regions, however, the maximum fall for one day may be taken as 0·15 m. in the plains and as 0·25 m. on mountains. The heaviest thunder-showers give a maximum rainfall of 5 mm. per min., but this only lasts for a very short time. The rain fall increases rapidly as we ascend mountains up to a certain height (1 to 2 km.), after which it again diminishes. In Germany we can assume that rain (or snow) will fall on from 150 to 200 days per year, according to the geographical situation.

§ 7. WIND.

Wind is air in a state of motion. A mass of air is caused to move when the pressures acting on it are not in equilibrium, this being usually due to differences of temperature. The movement of the air is not a steady flow, but occurs by fits and starts, varying both in strength and direction in the course of a few moments (Langley, *The Internal Work of the Wind*, 1893).

The direction in space from which the wind blows is called

the direction of the wind, and is determined by means of a weathercock. The velocity of the wind is judged either by the feel and its visible actions, in which case the Beaufort scale is in general use (0 = calm, 4 = strong wind, 8 = stormy, 12 = hurricane), or it is determined by suitable instruments. The momentary strength of the wind is given by a pressure anemometer (Hookes, Osler, Wild) or an absorption anemometer (Hagemann, Dines). The mean velocity of the wind is usually determined by means of the Robinson anemometer, consisting of a cross of hollow cups which is set in rotation by the difference in the pressure of the wind on the concave and convex sides of the hemispherical shells, the number of revolutions being recorded by a suitable counting mechanism driven by cog wheels. The relation between the true distance travelled by the wind and that travelled by the middle point of one of the hemispheres in its rotation must be determined separately for every anemometer, but it may be taken as about two to three times as far. The velocity of the wind is usually expressed either in m. per sec. or km. per hour (1 km. per hour = 0·28 m. per sec.). In the Appendix a table is given to enable the reductions to be conveniently made. The relation between the wind velocity, as measured by instruments, and the estimated velocity expressed on the Beaufort scale is rather a variable one, depending on the observer, but we may assume that the number on the scale gives about half the velocity of the wind in metres per second, except numbers 11 and 12, which correspond to considerably greater velocities (30 and 50 m. per sec. respectively).

While the mean yearly wind velocity on the ground in the interior of Germany is at most 5 m. per sec., or on the coast 6 m. per sec., the velocity may rise during a storm to 30 or 40 m. per sec. for a fraction of an hour, or at most an hour, although in tropical regions velocities as high as 60 m. per sec. are occasionally attained.

Extraordinarily great velocities (more than 100 m. per sec.), lasting for very short periods, are acquired by small masses of air in the case of tornados, the diameter of the disturbed region being at most some hundreds of metres.

An exact knowledge of the pressure of the wind, as also the relation between wind pressure and velocity, is still wanting. v. Lössl gives the relation

$$p = a\,\frac{F.v^2}{g}, \qquad (10)$$

where p is the pressure in kg. per sq. m., a is the weight of a cubic metre of air (= 1·293 kg. at 0° C. and 760 mm. pressure), g is the acceleration of gravity = 9.81 $^{\mathrm{m}}/\,\mathrm{sec}^2$., and F is the area in square metres, whence $p = 0·132\ v^2$ kg. per square metre. We may take

a pressure of 200–300 kg. per sq. m. as corresponding to the greatest wind velocity hitherto experienced.

The irregularities on the surface of the earth reduce the velocity of the air by causing friction, whence the wind is, in general, stronger on the sea than on the land, and stronger in the country than in the town, and increases very rapidly in velocity as we rise above the ground. According to Stevenson's experiments, carried out on a mast, the velocity of the wind at a height of 15 m. is twice that at a height of some decimetres, while, according to Fine's observations in Paris, it is twice as great at a height of 31 m. as at 7 m., and from Douglas Archibald's kite experiments increases rapidly at first, then, after 60 to 100 m. has been reached, more slowly ; on the Eiffel Tower (300 m.) it is four times as great as in Paris, which is, however, very sheltered. Berson finds, from the Berlin balloon expeditions, that the velocity of the wind

at mean heights of	ground	0·5	1·5	2·5	3·5	4·5	5·5 km.
has the relative values	1	1·8	2·0	2·2	2·5	3·1	4·5

At greater heights the increase may be determined from observations on the cloud movements. The most exact determinations can undoubtedly be made by the aid of balloons, more especially by the use of pilot balloons (Kremser, *Z. f. L.*, 1893). The same holds true for the directions of the air currents.

The prevailing direction of the wind is very different according to the geographical situation and the conditions prevailing at the time. The general distribution over the earth follows from the general circulation of the atmosphere (see below). In Germany the predominant winds blow from the S.W. or N.W.

With increasing height the direction of the wind turns almost regularly, especially quickly in the lowest strata, to the right. According to Berson's calculations from the Berlin ascents (75 per cent. show a turning to the right),

between heights of	0 & 1	& 2	& 3	& 4	& 5	& 6	& 7 km.
the deviation to the right is	15	13	11	1	3	6	6 degrees,

a total twist of 55° in 7 km., so that, for example, a S. wind on the grounds becomes a S.W. wind at a height of 7 km. Under certain conditions of the weather, deviations from these figures naturally occur, and sometimes there is a twist in the opposite direction, *i.e.* to the left as we ascend.

The observations hitherto made on the vertical movements of the atmosphere are too few and too unreliable to serve as a basis for any deductions. Certainly the vertical movements are much weaker than the horizontal, although they may perhaps, in big atmospheric disturbances, be the origin of storms. It is peculiar that the ascending currents appear to more than balance the descending ones.

§ 8. DISTRIBUTION OF PRESSURE. WIND AND WEATHER. WEATHER FORECASTS.

In order that the different pressures existing in two regions may be equalised, air must flow from the region of high pressure to that of low pressure,—and it will move the more quickly the greater the difference in pressure. In consequence of the spherical form and the rotation of the earth, a deflection of the movement of the air to the west is caused in the northern hemisphere, and to the east in the southern hemisphere, the magnitude of the deflection increasing with the velocity of the movement and with the geographical latitude. If one stands with one's back to the wind then, in the northern hemisphere, the region of low pressure lies to the left and somewhat in front, the high pressure region to the right and somewhat behind (Buys-Ballot's Law).

Theoretically the deflection in 1 second $= 2\ v\ \omega \sin \phi$, where v is the velocity in metres per sec., ω the angular velocity of the earth $= 0{\cdot}0000729$, and ϕ the geographical latitude. With increasing frictional resistance the deflection becomes smaller.

The rate of decrease of the atmospheric pressure in a direction perpendicular to the isobars, expressed in mm. of mercury per geographical degree ($=111$ km.), is called the barometric gradient. Guldberg and Mohn, *Études sur les mouvements de l'atmosphère*, 1876, deduced for the connection between the gradient and the velocity of the wind the following relation:—

$$v = \frac{0{\cdot}00012237 \,.\, \mathrm{G} \,.\, \cos \alpha}{\mathrm{K}a}, \tag{11}$$

where v is the velocity of the wind, G the gradient, α the angle of deflection, K the coefficient of friction, and a the mass of a cubic metre of air. (K was taken as $0{\cdot}00002$ for a calm ocean and $0{\cdot}00012$ for very irregular land.) The theoretical values for v prove to be almost twice as great as the values actually observed, and very dependent upon the situation of the observing stations. Sprung gives the following relation for places on the German coast:—

$$\frac{v \text{ in m. per sec.}}{\text{G. in mm.}} = 3{\cdot}8.$$

Examining the form of the isobars more closely, we see that they mostly represent closed curves. If the pressure increases as we go towards the centre, we are dealing with a *maximum*; if it decreases as we go towards the centre, we have a *minimum*. According to the above law the air flows out of the

maximum with a path deflected to the right in the Northern Hemisphere (an anticyclonic movement); while with a minimum the air flows towards the centre with a path deflected to the right (cyclonic movement). The distribution of the wind in the separate portions is therefore given at once. The mean angle of deflection in mid-Europe is about 45°. Since anticyclones have usually small, and cyclones usually steep, gradients, we have calm weather in the former case, windy in the latter case. In the interior of a cyclone the air has an upward motion, which causes it to cool rapidly, and consequently, sooner or later, according to the amount of aqueous vapour contained in it, to reach the dew point, when condensation and the formation of clouds occur and the temperature gradient becomes less; in the interior of an anticyclone the air has a descending motion, becoming in consequence warmer, causing the clouds rapidly to disappear as aqueous vapour. In the former case we may expect, therefore, dull rainy weather, and in the latter clear dry conditions to prevail. Clear dry weather greatly favours radiation, and causes, with defective or insufficient absorption of heat, intense cooling (temperature inversions, etc.), and condensation in the lowest strata of the atmosphere, through which the downward currents of air cannot penetrate, so that mist is readily formed; in winter and in the night-time also the sky is frequently overcast, even when a minimum exists. At considerable heights, from 6 km. upwards, observations on mountains and in balloons show that the air is warmer under anticyclonic than under cyclonic conditions in winter. Cyclones penetrate as a rule to greater heights than anticyclones.

The manner in which descending air becomes rapidly warmer and dryer, and ascending air rapidly cools to the point at which condensation occurs, is shown best when the current of air strikes against the side of a mountain. It is then compelled to ascend the mountain on the weather side, becomes consequently rapidly colder, and after a time saturated with aqueous vapour, cools less rapidly while condensation is taking place (about 0·5° C. per 100 m. of ascent); in the valleys on the leeward side, on the contrary, when the air is sucked down by a neighbouring depression, it descends often with considerable velocity and is warmed dynamically 1° per 100 m. descent, and, since it brings from the summit very little moisture, soon becomes extraordinarily dry and warm (Föhn).

At the base of the cyclone (Northern Hemisphere), the masses of air blow towards the centre with a deflection to the right from the gradients; with increasing heights they follow more and more closely the isobars, and at still greater heights flow outwards at an acute angle to the isobars to the left; at the base

of an anticyclone the movement is outwards and directed to the right, at greater altitudes being parallel to the isobars, and still higher being towards the centre at an acute angle to the isobars. A rotation of the movement thus takes place in a certain direction as we ascend.

Knowing the distribution of the winds in the various parts of the cyclones and anticyclones, and the character of the wind, from its origin, we can tell to a certain degree what the remaining conditions relating to the weather will be. These relations

FIG. 9.—Paths of barometric depressions.

will, however, alter from place to place according to the geographical situation.

In general continental winds bring in summer dry warm weather and in winter dry but cold weather, whereas sea-winds cause damp weather, and in summer cool, in winter mild, conditions. In Germany the advance of a cyclone with its south winds causes warm rainy weather, followed after the cyclone has passed by cooler winds, but better weather.

While pressure maxima, as a rule spreading over a wide area,

only slowly alter their positions, and therefore give constant weather, the minima, mostly covering only a small region, move fairly rapidly, usually from west to east. Their mean velocity in Europe is about 7–8 m. per sec.; in North America twice this. Bebber has found that in Europe minima follow most frequently the following paths (*cf.* fig. 9):—(I.) from North Scotland to the north-east, (II.) from the Shetland Islands eastwards across Scandinavia towards the White Sea, (III.) from the Shetlands south-east towards South Russia, (IV.) from a point south of Ireland either towards the east-north-east over Heligoland, and (IV^{a}.) over the Skagerrac, or (IV^{b}.) towards Finland; (V.) from points south of Ireland towards North Italy (V^{a}.), and from there either along the east coast of Italy (V^{b}.), or towards the Black Sea (V^{c}.), or towards the Baltic Sea (V^{d}.). I. and III. are most frequent in autumn and winter, IV. in summer and autumn, V^{a}. in the colder seasons of the year, and V^{b}. in spring and autumn.

With regard to the movement of depressions as a whole, two laws may be given: (1) The motion takes place approximately in the direction given by the resultant of the motions of the various masses of air contained in the depression (in the whole vertical extent) (Köppen); (2) A depression moves most easily in a direction such that it has the highest pressure and higher temperatures on the right-hand side (Ley).

On the basis of theoretical and empirically deduced facts it is possible, knowing the state of the weather over a large area, set out on suitable charts and maps, to forecast the weather for a short time, about twenty-four hours, with a certain high degree of accuracy.

In order to forecast the weather conditions with any degree of probability for longer periods in advance, it is necessary to make use of other aids. It is necessary to calculate the probable duration of the existing weather conditions, and to follow the relations between the weather phenomena at widely different regions of the surface of the earth and sea (*e.g.* the Gulf Stream and Europe). Above all, a study of the positions of the great permanent centres of high and low pressures in the atmosphere will be of the greatest value in helping us to make forecasts for several days in advance. The average character of the weather over Europe, for example, depends principally on the mean position and the *seasonal* displacements of the following centres of action:—(1) the pressure maximum near the Azores; (2) the pressure maximum over Siberia in winter; (3) the pressure minimum over the ocean in the north-west of Europe; and (4) the pressure minimum over the Mediterranean. The following meteorologists have made investigations on the influences of these centres:—Hoffmeyer, *Influence of the North Atlantic*

Minimum; Teisserenc de Bort, *Types of Winter Weather*; and van Bebber, *The Different Regions of High Pressure and the Weather in Europe*. For further details, special treatises on the subject may be consulted.

§ 9. GENERAL CIRCULATION OF THE ATMOSPHERE.

It is being shown more and more clearly every year that the circulation of the atmosphere in our latitude cannot be thoroughly explained by considering only maxima and minima due merely to local influences. On the contrary, the general circulation of the atmosphere over the whole globe, due principally to the differences of temperature existing between the poles and the equator, modified, of course, by the distribution of land and sea, is recognised as exerting the most important influence over the local circulation.

As already stated, we find at the equator, where, in consequence of the intense action of the sun, the whole vertical column of air is strongly heated, and, therefore, at its upper surface flows towards the pole, a relatively low barometric pressure; up to a latitude of 30° or 40°, where the air coming from the equator is stemmed and sinks, it gradually increases, finally decreasing again as we go polewards (not quite to the pole, however, where, in consequence of the continental character of the surroundings (ice), the lower strata of the atmosphere are strongly cooled, causing a noticeable increase in the barometric pressure). On the basis of the general distribution of pressure on the earth's surface, as well as the currents of air at great elevations set up by this distribution, taking into account also the temperature and humidity of these masses of air, we have in the northern hemisphere, between the equator and a latitude of about 35°, north-east winds, and in the southern hemisphere south-east winds; but at great heights the currents in the northern hemisphere are south-west and in the southern hemisphere north-west. At the equator itself, with its ascending masses of air, we get heavy clouds and rain, but a calm zone on the surface of the earth, though aloft there will be an east wind blowing, which, with increasing latitudes, turns more and more to the north-east or south-east according as to whether we are in the northern or southern hemisphere.

There is also a calm zone in latitude 35° (north and south), but with descending air, dry and clear weather. Up aloft the south-west winds continue (in the southern hemisphere the north-west winds) also on this side of latitude 35°, gradually, in consequence of the rotation of the earth, becoming pure west winds in higher latitudes. In the lower strata, also, from

latitude 35° onwards, we get the south-west (or north-west) current, finally becoming a west wind, until in the polar regions more northerly (or southerly) winds arise. In the middle strata of the atmosphere, the air carried polewards after latitude 35° must return to the equator as a north-west wind in the northern hemisphere or a south-west wind in the southern hemisphere. This last current complicates the phenomena, and the general distribution of wind will be most clearly seen by the following table given by Hann :—

Geographical latitude.	Wind on surface of earth.	In the middle strata, 3–10 km.	In the upper strata, > 10 km.
60° N.	W.S.W.	W.N.W.	W.S.W.
30° N.	N.E.	S.W.	W.S.W.
10° N.	E.N.E.	E.	E.S.E.
Equator.			
10° S.	E.S.E.	E.	E.N.E.
30° S.	S.E.	N.W.	W.N.W.
60° S.	W.N.W.	W.S.W.	W.N.W.

This general wind system will be influenced on the one hand by local circulations (cyclones and anticyclones), especially in our latitudes, and on the other hand by far-reaching modifications, caused more particularly by the different effects set up by the radiation of the sun on continent and ocean (monsoons). In summer the overheating of the continents—especially the Asiatic continent—causes an ascending current of air above them and currents of air flowing in from the sea, whereas in winter the extreme cold causes an increase in the density of the air, a barometric maximum, and, therefore, a flow of air outwards, with a deflection to the right in the northern hemisphere.

It may be finally noted that the change of the seasons—that is, the varying position of the sun—must cause corresponding displacements in the plan of the general circulation and an alteration of the wind velocities.

§ 10. ANNUAL AND DAILY CHANGES IN THE METEOROLOGICAL ELEMENTS.

(*a*) **Barometric pressure.**—The annual variation is very different at different places, being the greatest over continents,

where the strong heating causes a minimum in summer, and the strong cooling a maximum in winter, while on the oceans these alterations are in the opposite sense and very much less pronounced. The higher strata show a maximum in summer and a minimum in winter, since in the first case a greater quantity of air is lifted into the higher niveaux owing to the heating of the masses of air, while in the latter case more air is pressed downwards owing to the cold.

The daily variation is usually, except in tropical regions, masked by the more irregular alterations, and is only of small magnitude (the amplitude being at the most 3 mm.); almost everywhere on the earth it shows a double wave, varying somewhat with the season, but having a principal maximum at 9–10 a.m., a minimum at 4–5 p.m., a second maximum at 10–11 p.m., and a second minimum at 4–5 a.m. The daily amplitude decreases as we go from the equator towards the poles.

On lofty mountain peaks the daily variation of the barometer is entirely altered owing to temperature influences, and follows more or less the variations of temperature.

(*b*) **Temperature of the air.**—Except in the tropics the annual range of temperature shows only one maximum and one minimum, corresponding to the position of the sun, though showing a considerable lag which is greatest on the oceans. The yearly amplitude is considerable in the interior of continents, small on the ocean, in the tropics, and at great heights.

The daily range shows also only one wave: Maximum—on continents, 2–3 p.m.; on oceans, 12–1 p.m., Minimum—on continents, about sunrise (in winter a little before and in summer a little after it); on the ocean one or two hours earlier. The amplitude decreases with the height above sea level (especially in the free atmosphere) and with the cloudiness, which prevents extremes of temperature; continents, valleys, and a clear sky increase the amplitude.

(*c*) **Humidity.**—The annual variation of the absolute humidity (of great amplitude) depends principally on the temperatures, and varies in the same manner; that of the relative humidity varies almost in the opposite sense except on high mountains.

The daily variation of the absolute humidity (of small amplitude) follows on the sea that of the temperature, and in winter also on the land, on which in summer the absolute humidity increases from sunrise only to 9 a.m., then falls until 3 p.m., to reach a second maximum about 9 p.m.; the daily variation of the relative humidity (of great amplitude on the land) is opposite in sense to that of the temperature.

(*d*) **Cloudiness** has an annual variation varying enormously

from place to place. In general it is more dense in the colder seasons than in the warmer, a minimum mostly in May or September, a maximum in November or December.

The cloudiness is usually a minimum in the evening and a maximum in the morning (in winter) or at mid-day (in summer).

(*e*) **Rainfall.**—The annual variation is very different in regions possessing different climates. In our zone the rainfall is a maximum inland in summer and a minimum in winter, but on the coasts it is a maximum in autumn and a minimum in spring. On mountains the winter rainfall is the largest.

The daily period is complicated, and varies from place to place. On the coast it is usually a maximum in the night-time and a minimum at midday, whereas in the interior the principal maximum occurs in the afternoon and the minimum towards midday. The period of the day when the temperature is increasing is the dryest.

(*f*) **Wind.** — The general circulation of the atmosphere, combined with the air currents produced by differences of temperature existing between land and water, cause an annual period of the wind, both as regards direction and strength, varying with the zone and geographical situation. For North Germany the percentage frequencies of the principal winds in summer and winter are the following (according to Hann):—

	N.	N.E.	E.	S.E.	S.	S.W.	N.	N.W.
Winter,	6	7	9	11	15	24	18	10
Summer,	9	8	6	7	10	22	20	18

The strength of the wind is greatest in winter and least in summer (with a lag in the interior), as is also the frequency of storms, which show no marked maximum about the equinoxes.

The direction of the wind in its daily period, according both to observations taken on plains and on mountain stations and on towers, follows the sun ; this is only in part in agreement with theoretical considerations, according to which the direction of the wind should turn with the hands of a watch up to midday, and afterwards turn against them—though only in the plains, and not on mountain peaks. If not disturbed by powerful general air currents, the daily period of the direction of the wind on the coasts is very regular and striking, since the surfaces of equal barometric pressure rise and fall in consequence of the marked daily period of temperature over the land, giving rise to land and sea breezes—on the surface of the earth towards the sea at night, in the day towards the land, though in the opposite directions at a height of a few hundred metres. Similarly we get in mountainous regions downward currents of

air into the valleys in the night, and upward currents during the day.

The strength of the wind attains a maximum on land shortly after midday, and is a minimum in the night; on mountain peaks, on the contrary, and in the free atmosphere as soon as a height of 100 m. is reached, we have a minimum about midday, while a maximum is found in the night; finally, on the ocean the wind blows with about the same strength throughout the day and night. (For further details respecting the annual and daily periods of the strength of the wind, see Hellmann, *Met. Zeitschr.*, 1897 and 1899.)

§ 11. ELECTRICAL PHENOMENA.

Electricity is always present in the atmosphere. Numerous experiments have been made bearing on the origin and nature of atmospheric electricity, and various theories have been propounded to explain it; the modern ionic theory seems the best founded and to promise a complete solution of the problem. (See Ebert, "Die Erscheinungen der Atmosphärischen Elektricität vom Standpunkte der Ionentheorie," *Met. Zeitschr.*, 1901.)

Observations show that in dry weather the atmosphere is positively charged—that is, it is at a higher potential than the earth's surface; only during a rainstorm is it found to be negatively charged.

A large annual and a feeble daily period of potential are found: the potential gradient is steepest in winter, smallest in summer; in the course of the day we have two maxima (morning and evening), and two minima (afternoon and night), of intensities which differ from place to place, and the amplitudes of which diminish with the height. In the free atmosphere the potential gradient becomes smaller and smaller the higher we go, and seems to disappear altogether at a comparatively low height (according to Baschin and Börnstein's balloon observations, between 3 and 4 km.). There are consequently quantities of positive electricity present in the atmosphere outside the earth. As to whether their seat is to be found in the lower or upper strata is as yet an open question. Exner found that the fall of potential decreased regularly with the amount of aqueous vapour present, and Elster and Geitel found that it decreased with the increase of the intensity of the ultra-violet radiation from the sun and also with the increase of transparency of the air. Various relations between the atmospheric electricity and temperature have also been found.

The most suitable apparatus for measuring the fall of potential

is Exner's Electroscope (Exner, *Über transportable Apparate zur Beobachtung der atmosphärischen Elektricität*, 1887).

In order to explain the loss of electricity from a charged insulated body and the conduction of electricity in gases, we assume that in the molecules themselves we have freely moving bodies (ions), which are charged, some negatively and some positively, and which move in the direction of the lines of force in the electric field with different velocities. If a particle charged with one kind of electrification is attracted to one charged with the opposite kind, they neutralise one another, and give up their charges to one another, and are no longer electrified. The more ions we have present the greater will be the loss of electrification, and the smaller therefore the potential gradient. On the assumption that there are large numbers of these charged ions (+ and −), having different velocities, many of the phenomena accompanying atmospheric electricity can be immediately explained.

A great deal of notice has been taken lately of the dissipation of electrical charges, which can be conveniently measured by an apparatus constructed by Elster and Geitel which is suitable for balloon work. The ionisation of the air is attributed to the action of the ultra-violet light, which is most powerful in the upper strata.

The normal potential gradient shows irregular and large disturbances on the appearance of rain clouds, in which, therefore, great quantities of electricity must be stored up. These have their influence on other clouds and on the earth, repelling electricity of the same sign and attracting that of opposite sign. If the force is great enough, the resistance of the air is broken down and lightning discharges ensue.

Franklin's kite experiments proved the identity of lightning with electric discharges (which may also be shown by means of captive balloons). The lightning, usually some kilometres in length, causes the air along its path to expand, either by heating effects or effects in the nature of a mechanical explosion, and the rushing in of the surrounding air into the partially evacuated space gives rise to thunder. Lightning and thunder together, usually accompanied by heavy rain, often by hail, form what are called thunderstorms. Three varieties of lightning may be distinguished:—zig-zag or forked lightning (a main streak with side projections, appearing on a photographic plate like the network of a river basin), sheet lightning (the lighting up of the whole cloud), and globe lightning (rare). Their colour is usually a ruddy violet. Common summer sheet-lightning is usually the reflection of a distant flash, though perhaps an independent phenomena. The thunderclap travels on with the velocity of sound (333 m. per sec. at 0° C.), and can be utilised

to find the distance away of the storm. The roll of thunder is explained by the length and form of the lightning, remembering the comparatively slow rate of propagation of sound and the interference of the separate portions of the lightning's path, as well as by the action of echoes. The number of lightning flashes and thunder-claps varies. In Prussia two hundred buildings out of a million are annually struck by lightning, and five persons in a million killed by it. According to von Bezold the number of cases of damage by lightning in Bavaria has increased sixfold since the thirtieth year of the previous century. Thunder-clouds consist of heavy blue-grey cumulo-nimbus clouds, covered by a white kind of cirrus cover (false cirrus), while underneath small broken clouds move rapidly about. Thunder-clouds may sink very low indeed, but they have been seen piled up to a height of over 10 km.

We distinguish between thunderstorms due to cyclones and those due to heat. The former belong to the interior of deep depressions, and therefore generally to stormy, overcast weather, being most frequent in the colder periods of the year and day, occurring oftenest at sea. The latter form on the boundaries of high and low pressure regions in still air with good insulation, and most frequently in the warmer periods of the year and day and on the land. The known phenomena accompanying thunderstorms—rapid variations of barometric pressure, alterations of temperature, heavy rainfall, hail, etc.—are most plausibly explained by the assumption that supersaturation and supercooling take place in the higher strata of the atmosphere (von Bezold, *Zur Thermodynamik der Atmosphäre*, IV. "Gewitterbildung"). The greater number of thunderstorms come to us from the west or south-west. Those coming from these directions travel also most rapidly. As a rule, the velocity of their motion varies between 30 and 40 km. an hour. Often the thunderstorms spread and gradually break up, though sometimes they travel over a long stretch of country. Thunderstorms are most frequent in the tropics, and diminish markedly with increasing latitude, although irregularly. In Germany thunder occurs on 10–25 days per annum.

The steady discharge of electricity at a high potential from points is called St Elmo's Fire, *e.g.* the discharge from masts, towers and other lofty buildings, to a low-lying thunder-cloud. The discharge takes the form of a small brush of flame about 1–10 cms. long: if the object is positively charged it has a ruddy hue and spreads out widely, while if the object is discharging negative electricity it is not more than 1 cm. long, violet in colour, and is much more compact.

The Aurora Borealis must be considered also as an optical phenomenon of electric origin. According to Paulsen it is a fluorescent

phenomenon like that of cathode rays. Its form and intensity vary enormously. Usually it shows itself at the magnetic North Pole as a dark segment of a circle surrounded by a bright edge, with curtain-like bands spreading out from it; from the border bright streamers are shot out radially, often stretching to the Northern Lights (corona). The height of the phenomenon varies from a few km. up to 200 km. The frequency of the appearance, its form and brilliancy, increase as we go polewards, but diminish again near to the pole itself. On account of its disturbing effect on the compass needle, Humboldt has termed it a magnetic storm. In many important respects the Aurora Borealis has been shown to be closely related to the presence of sun spots, possessing the same period of eleven years, whereas no other phenomenon of the atmosphere has hitherto been shown to have any certain or practical connection with phenomena on the sun.

§ 12. OPTICAL PHENOMENA.

The vault of the sky does not appear hemispherical, but rather as a segment of a sphere, whose horizontal radius is more than three times the height. The colour of the sky is usually blue; this blue colour can be explained by the presence of immense numbers of small foreign particles in the air, from which the blue rays of the sunlight are much more strongly scattered than the rays of longer wave length, the more so the smaller the particles (which is the case at great heights where the blue colour is much deeper); the rays of longer wave-length, on the other hand, pass through the atmosphere in larger numbers, and cause the transmitted light, especially if it has to pass a long distance through the atmosphere (*i.e.* on the horizon), to be of a yellow or red hue (morning or sunset glow). This only holds true so long as the particles are smaller than the shortest wave-length of light (0·00035 mm.); larger particles reflect the light, and if present in large numbers, cause the illuminated region to appear as white as the source of the light itself, as is the case when large drops of water are present, or quantities of dust carried up in a storm.

Daylight is caused by the scattered light diffused through the air; if there were not this diffuse reflection the sun would appear as a glaring bright disc on a dark background.

Being a diffusely reflected light, the light of the sky is polarised. For the parts of the sky lying near the horizon the vibrations of the light are perpendicular to the plane drawn through the sun, the observer, and the point under observation. Some points are neutral: Babinet's point (20° above the sun), Brewster's (20° beneath the sun), and Arago's (20° above the pole of the sun).

On account of the diminishing density of the strata of air lying above one another, rays of light are refracted somewhat before they reach our eyes, causing all objects to appear raised above their actual positions, the more so the nearer they are to the horizon, so that we can see even bodies which are beneath the horizon. If two layers of air of very different densities lie above one another (caused by intense local heating), rays of light which make an acute angle with the bounding surface may be totally reflected, and so cause inverted images of distant objects to appear (mirage). Since masses of air of different densities are almost always moving through the atmosphere, we almost invariably notice a wavering or distortion of distant objects, such as the twinkling of stars (scintillation).

After sunset (and before sunrise) the upper regions of the atmosphere, with their numerous dust and water particles, are still illuminated by the rays of the sun, causing a general illumination for some little time (**twilight**). It is consequently possible to read out of doors until the sun is about 6° beneath the horizon (simple twilight), and the last shade of brightness only vanishes when the sun is 16° beneath the horizon (astronomical twilight). On account of the bending, reflection, and refraction of sunlight there are various phases of twilight. Normally (according to von Bezold, *Annalen der Physik u. Chemie*, vol. 123) the bright segment appears first on the western horizon, whereas on the eastern horizon we have a dark segment, owing to the shadow cast by the earth appearing out of the violet glow which previously filled the eastern horizon. The shadow of the earth rises rapidly and twilight fails; 20–25 minutes after sunset the bright segment is filled with a pale purple disc of large diameter (30–40°), the purple light. It begins when the sun is about 3° below the horizon, sinks gradually behind the bright segment, and vanishes when the sun has sunk to 6°, which marks the close of ordinary twilight. In clear weather, and with numerous dust particles in the air, the whole appearance is repeated after some time (half an hour), although feebler in intensity; a second dark and a second bright segment appear, and a second purple light (position of the sun $-7°$ to $-10°$). This last phenomenon was most striking after the eruption of Krakatao in 1883. The small particles in the higher atmosphere caused by this eruption not only strengthened the purple light and other twilight phenomenæ, but also caused the appearance of a red-brown ring round the sun (and moon), which was brightest at a distance of 14° from the sun and extended to about 25°. It must be regarded as a refraction phenomenon. In a similar manner the small halos round the sun and moon, with their many-coloured borders, owe their origin to refraction by the dust or water particles in the atmosphere, the smaller these

are the larger being the halos or coronas, the inner portion being violet and the outer red, the relation between the angular distance from the sun α, the diameter of the particles d, and the wave length of the respective light λ, being given by

$$\sin \alpha = \lambda/d.$$

The large rings around the sun and moon (**halos** of 22° and 46° radius), as well as parhelia, mock moons (paraselenæ), etc., may all be explained by the reflection and refraction of the light by hexagonal ice crystals in the upper strata of the atmosphere (Galle, "Über Höfe und Nebensonnen," *Pogg. Ann.* 1840).

Glories are coloured rings seen round the shadow cast by a balloon on the clouds. They can be explained by the refraction of the light in the droplets forming the cloud, and the ultimate return of the rays of light to the observer, to whom they appear to originate in the cloud itself.

The **rainbow** is seen on the opposite side of the sky to the sun, if there is a raining cloud there, as an arc of a circle whose centre lies opposite to the sun. It is caused by the refraction and reflection of sunlight in the droplets and the emission of a portion of the light as a parallel beam of rays towards the observer. The red of the rainbow subtends an angle of 42½°, the violet 45°. A double reflection in the drops causes a feebler secondary bow (diameter about 54°) to be seen with the prismatic colours reversed in position. Tertiary bows are also sometimes seen. Pernter has developed a complete theory of the rainbow, and has traced the diverse phenomena to the different sizes of the drops. (For a more complete treatment see Mascart, *Traité d'optique*, tome iii., 1894, or *Pernter's Meteorologische Optik.*)

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CHAPTER III.

METEOROLOGICAL OBSERVATIONS IN BALLOON ASCENTS AND THE COMPUTATION OF RESULTS.

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§ 1. INTRODUCTORY.

THE character of the observations to be taken during ascents for meteorological purposes has already been indicated in the previous chapters. Special investigations and observations, such as those on atmospheric electricity, magnetic, spectroscopic, or microscopic researches, are usually left to specialists in these subjects, and are outside the scope of true meteorology. As a rule only the ordinary meteorological elements are to be observed, and in the present chapter we will confine ourselves solely to these.

§ 2. OBJECT OF DIFFERENT FORMS OF ASCENTS AND THEIR ORGANISATION.

Captive balloons (such as the Sigsfeld-Parseval kite balloon) are best adapted to the determination of the physical conditions in the lower regions of the atmosphere, and especially for the examination of one particular region over a lengthy period of time. The same purpose is served by *kites*, carrying recording instruments; kites, however, require at least a fair breeze for their ascent, but by using several kites attached tandemwise to a line, heights of 4 km. have been reached, enabling simultaneous observations to be made at different heights.

Manned free balloons enable the meteorological conditions to be studied at all heights up to 10 km., and their variation with the height within a very short time to be determined, while the horizontal variations are obtained by the *simultaneous ascents* of several balloons at widely separated stations, thus enabling

the horizontal distribution of the various meteorological elements to be mapped out for various altitudes, and to be compared with the conditions prevailing at the time on the earth's surface.

Pilot balloons are useful only for observations on the direction and velocity of the air currents at different heights, but when carrying recording instruments (*ballons sondes*), they serve most of the purposes of a manned balloon, and often reach heights utterly unattainable by man (25 km. or more). Of course the many useful personal observations obtained in manned balloon ascents, which cannot possibly be recorded automatically, are not obtained by the use of the *ballons sondes*.

In order to make all these ascents as productive as possible, it is necessary to have the complete and exact meteorological data for the whole of the district in which the balloons are sent up for the time during which the ascent lasts, and it is also desirable to have a thorough knowledge of the weather conditions prevailing at corresponding heights on neighbouring mountains. On this account it is necessary that all the meteorological stations work in unison on the days of the ascents.

In recent years, under the auspices of the International Aeronautical Commission (President, Professor Dr Hergesell of Strassburg), *international simultaneous ascents* of the various types of balloons and kites have been made on the first Thursday of each month, and have given results of the highest importance. The German stations participating in these ascents are Berlin (Aeronautical Observatory and the Balloon Battalion), Munich, and Strassburg.

§ 3. THE OBSERVER.

Apart from a sufficient general education, the observer must have had practical experience in taking observations and reading the instruments. Calmness and carefulness are also obvious recommendations. Before the first ascent, gymnastic exercises should be practised. Warm clothing must be taken as a protection against probable cold, as well as provisions (warm, when possible, for long trips). Before the first lofty ascent (greater than 5 km.) a medical examination is to be recommended. For great heights it is necessary to take a supply of oxygen, usually in steel cylinders fitted with suitable respirators, or, still better, Cailletet's oxygen respiration apparatus.

§ 4. THE INSTRUMENTS.

We shall not go into the construction, working, and calibration of the recording instruments used for unmanned balloon

ascents, but will briefly describe the instruments used in manned balloons. It may be noted, however, that when *ballons sondes* or *registering balloons* are sent away, directions should always be attached giving full instructions to the finder as to the care of the instruments. For a manned ascent the following instruments are required :—A watch, an aneroid or mercury barometer and perhaps a barograph, a thermometer (psychrometer) and perhaps a thermograph, a compass, accurate maps of the country to be passed over, and, finally, whenever possible, photographic apparatus and an anglemeter, *i.e.* a simple instrument to measure angular heights.

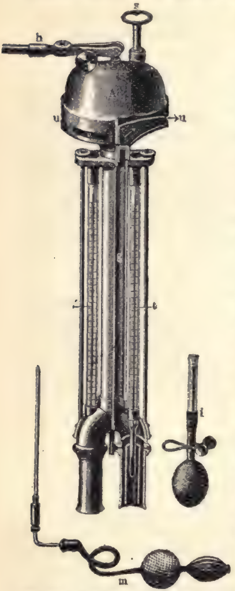

FIG. 10.—Assmann's ventilated psychrometer.

The *aneroid* must be carefully constructed, and compensated as perfectly as possible against the influences of changes of temperature. The *mercury barometer* used must have a large mercury receptacle, on account of the low pressures met with. For the recording barometer Richard's *barograph* answers perfectly. The mercury barometer must be tested under the air pump at low pressures, and the aneroid and baragraph should be compared with this during the course of the journey, as well as calibrated previously under the air pump at pressures and temperatures of the same order as those which may be expected at the heights to be reached during the course of the ascent.

The corrections for the *thermometers* (below $-38°$ C. an alcohol thermometer must be used) should also be determined beforehand. On account of the stillness of the air through which the balloon moves, only well-ventilated thermometers will give the true temperature, and these must be protected against the sun's radiation. In a case of necessity a thermometer which can be

revolved rapidly through the air may be used, but *Assmann's ventilated psychrometer* (fig. 10) is really an absolute necessity for all scientific balloon work. In this the thermometer bulbs are surrounded by thin highly polished tubes leading to a common central tube ending in a bell-shaped vessel at the top, in which is situated a small fan. This is set in rapid rotation by clockwork, which requires rewinding every five or ten minutes, and draws air through the apparatus past the thermometer bulbs with a velocity of 2 to 3 metres per second.

The apparatus usually contains two thermometers, one of which gives the true temperature, while the bulb of the second is covered with muslin moistened from time to time with water and serves for the determination of the humidity. Special practical arrangements to keep the muslin moist have been devised by the manufacturers (Fuess of Steglitz) of the instruments. In balloon work it is advisable to use ventilated psychrometers with three thermometers, two of which are used alternately for wet bulb determinations, so that while the one is being moistened the other may be ready for use.

The *photographic apparatus* has to serve for photographs of the underlying country, the clouds, and any special phenomena. A yellow screen is indispensable.

The *meteoroscope* (often consisting of a divided circle with a plumb line) can be very serviceable in measuring angular distances and their differences,—for clouds, optical phenomena, landmarks, etc.

In order to gain some idea of the alteration in the intensity of the strength of the sun's radiation, it is useful to have a black bulb thermometer in a vacuum, though more exact measurements may be taken with one of the latest forms of *actinometers* (*e.g.* that of Angström).

For reading the instruments in night expeditions, it is, of course, only permissible to use *electric glow-lamps*, though perhaps the newest kinds of luminous paint might afford sufficient light.

§ 5. DISPOSITION OF THE INSTRUMENTS.

The instruments must all be firmly attached to the car or ropes, in order to prevent any chance of their falling out, and must be so placed that all are convenient for reading. The barometer may be bound to the supporting cords, care being taken that the scale faces the observer; it must be protected against direct radiation from the sun by a screen. The ventilated thermometer is held at a distance of 1 or 2 metres

from the car of the balloon by suitable supporting rods, arranged so that it can be drawn to the car when it is necessary to wind up the clockwork; the thermometers can be read by a telescope rigidly attached to the framework of the car, but it is really essential to have some convenient means of winding up the clock

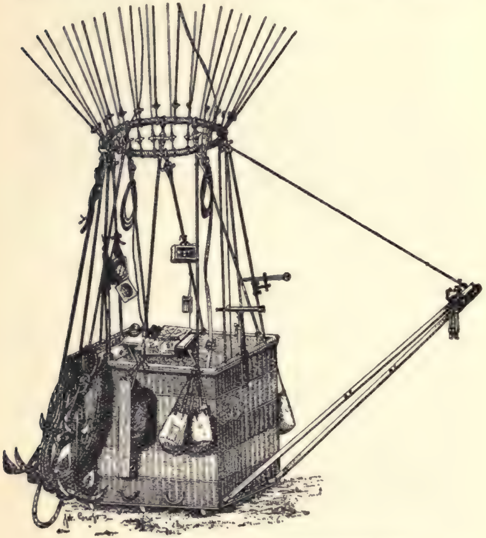

FIG. 11.—Balloon equipped for meteorological work.

and of keeping moist the muslin of the wet-bulb thermometer without much loss of time. The water for moistening the wet bulb should be kept in an inner pocket to prevent its freezing. The compass may be placed on the edge of the car. The radiation thermometer should be attached to one of the supporting ropes in such a manner that the sun's rays always

shine directly on to it. A convenient way of disposing the several pieces of apparatus is shown in the accompanying fig. (11).

§ 6. THE OBSERVATIONS.

It is best to prepare a *definite scheme* for recording the observations by dividing a piece of stiff ruled cartridge paper into vertical columns, at the head of each being written the nature of the observation or the name of the instrument whose readings are given in the corresponding column. See example on the following page.

The cartridge paper is conveniently supported by a string thrown round the neck, and each reading is recorded in its proper place, together with the exact time at which it is taken, leaving nothing to be remembered for any length of time. In the case of instruments such as the aneroid and the thermometers the readings should be taken at regular intervals (about every five minutes), except under special circumstances, such as during the passage through and on the edges of a cloud, when observations should be taken as frequently as possible. The aneroid and the thermometer should be read simultaneously, most conveniently by two observers (the balloon conductor reading the aneroid), though with practice one observer should be able to attend to the whole of the instruments. The winding up of the clock and the moistening of the wet bulb thermometer should be done a few minutes before the following observation is due. A single winding up lasts for five minutes, and the damping of the muslin for ten to fifteen minutes. When the temperature is below 0° C. the second wet bulb thermometer should be moistened every ten minutes alternately with first one, so that each has been moistened about eight or nine minutes before it is read. (For more exact details, see Assmann's article in the *Protokoll der internationalen aëronautischen Kommission*, Strassburg.) The readings on the *radiation thermometer* and observations on the *sunshine* (⨀) and the *clouds* (Index 1 denotes feeble, index 2 strong or dense clouds) may be made as convenient, though all changes should be noted. The following abbreviations are usually adopted for the various types of clouds :—

Cirrus . . .	Ci.	Cumulus . .	Cu.
Cirro-stratus .	Ci.-str.	Alto-cumulus .	A.-cu.
Cirro-cumulus .	Ci.-cu.	Cumulo-stratus .	Cu.-str.
Stratus . .	Str.	Nimbus . .	N.
Alto-stratus .	A.-str.	Cumulo-nimbus .	Cu.-ni.

The phenomena to be observed principally are the formation,

SPECIMEN OF SCHEME FOR MANNED BALLOONS.

Ascent of the balloon "Barbara," 15th May 1901. *Observer*—ELIAS.

Time.	Aneroid.		Mercury Barometer.		Thermometers.			Radiation Thermometer.	Sunshine.	Clouds. Extent 0–10, Density 0–2, and type.		Point on earth vertically beneath balloon.	Special remarks.
	Temp.	Pressure.	Temp.	Pressure.	Dry	Wet 1st Ther.	Wet 2nd Ther.			Above.	Below.		
h m	°		°		°	°		°					
2 10	8	651·2	...	...	5·3	3·8	...	12·1	⊙°	7^1 Cu	0	...	
15	8	645·1	...	...	4·9	3·9	...	11·0	⊙°	8 ,,	0	Nauen	
17	7	643·3	...	...	4·7	4·2	...	10·5	...	10 ,,	0	...	
19	7	640·9	...	...	4·5	...	4·5	8·2	...	10 ≡	10	...	In the clouds.
22	7	639·1	5	638·3	4·0	...	4·0	8·2	...	10 ≡	10	...	In the clouds.
25	6	636·0	...	...	4·3	...	3·5	13·3	$⊙^2$	2^0 Ci	8^1 Cu	...	Above the clouds.

disappearance, and alteration in form of the *clouds*. The *point of country* vertically beneath the balloon should be observed from time to time, when possible, and compared with the map, in order to obtain the direction in which the balloon is moving. The anchor lines serve as a useful line of vision to get the point vertically underneath the balloon, and the times at which the balloon passes over any recognisable place should be noted. If any precipitation or other phenomenon occurs, the following *international symbols* of notation may be used with advantage :—

● rain.
✳ snow.
▲ hail.
△ sleet, drizzle.
← frost needles.
≡ fog.
≡ ground fog.
∞ mist.
⊕ corona round the sun.
⊖ halo round the sun.
⊟ corona round the moon.
∈ halo round the moon.
⌒ rainbow.
Ʀ thunder.
< lightning.
⊙ sunshine.

The *mercury barometer* should only be used as a control instrument, and must consequently be read simultaneously with the aneroid. This should, however, only be done at points on the ascent where the rate of change of the velocity upwards is zero, *i.e.* when it has no acceleration, as, for example, when it remains at the same height for some little time. Where barographs and thermographs are used to confirm the instruments, *marks* should be made on these occasionally at noted times so that the readings may be accurately compared with the aneroid and psychrometer.

The barometer observations form the basis of the calculation of the height. Under certain circumstances it is possible to determine the *height without the aid of a barometer*, and it may prove useful to describe here briefly the other methods of height determination which are capable of practical adaptation. The height may be very roughly determined by an echo from the earth's surface (a method sometimes useful in a fog over mountains); if t is the time in seconds required for a sound directed vertically downwards from a trumpet, say, to reach the ear of the aeronaut after reflection from the earth, the balloon is approximately $330 . \frac{t}{2}$ metres above the land. More exact values are given by measurements of the angular distances between known landmarks on the earth's surface, whose distance apart can be measured out on the map. The observations and the calculations are simplest when the angular distance between the point of land momentarily below the balloon and another

well-marked point at a known distance away is measured. If D is the distance between the two points and α the angle of depression of the second point, the height is given by

$$H = D \tan \alpha.$$

A still more exact value for the height can be obtained from a photograph of the country lying beneath, but this method cannot be used to determine the height for immediate use. The method may be employed to give a continuous record and so, under certain conditions, replace a barograph (Cailletet, *Registrierapparat*, *I. A. M.*, 1898).

All these methods of determining the height from the balloon itself are far behind the barometric method in point of accuracy. An accurate control of this latter method is very desirable on theoretical grounds, and could be readily made by observations on the path of the balloon from the earth's surface, which would give not only the height but also the direction and velocity of motion. It is in this case necessary to distinguish between micrometric and purely trigonometric observations. The micrometric measurement of the apparent diameter of the balloon and the simultaneous determination of the angular height (and the azimuth eventually) is made by one observer only, and is liable to several sources of error, so that this method can only be applied for rough tests of the accuracy of the formula (for pilot balloons or *ballons sondes*). On the contrary, a careful trigonometrical survey of the path of the balloon from two or more points would lead to extremely useful and important results. The dromograph, invented by Hermite and Wurtzel, records automatically the angular altitude and azimuth, and simplifies the observations. It is really a necessity for several of these accurate tests of the barometric height formula to be carried out.

§ 7. THE COMPUTATION OF RESULTS.

(*a*) Calculations.—The *corrections* determined in part before and in part after the ascent must be applied to the readings of the pressure. If the aneroid has been compared with the mercury barometer during the ascent, the readings of the latter must be reduced to 0°, and if great exactness is required, allowance made for the alteration in the value of gravity. The corrections for the aneroid (and barograph) are made from the corresponding readings on the mercury barometer taken during the course of the ascent. The readings on the aneroid lying between points which were compared with the mercury barometer must be corrected by an amount equal to the mean of the corrections necessary at the two neighbouring standardised points, or, to be still more accurate, the alteration in the corrections

at the two points should be divided proportionately to the alteration of pressure for readings lying between them. The value of the pressure thus obtained may be applied to the *calculations of the altitude.* If observations have only been obtained at widely differing times and distance, each must be considered with reference to the atmospheric pressure on the surface of the earth immediately under the balloon, and use made of one of the barometric formulæ (given in Chapter II.), or of the barometric height table (see Table XII.) in Appendix. If the temperatures observed in the balloon do not permit of an exact mean being found, the mean temperature of the column of air may be taken as the mean of the temperature in the balloon and that on the ground beneath. In this way the height above the underlying land is obtained, and, adding the height of this, the height of the balloon above sea level.

When numerous observations rapidly following one another have been obtained, it is much more accurate and shorter to reckon the corresponding differences of level step by step, the mean temperature of each layer being determined, in this method, with great exactness from the observations. The sum of the single differences of level gives the total height. (For a complete account of this method, see Teisserenc de Bort and Hergesell in the *Protokoll der Internationalen Aëronautischen Kommission*, Strassburg.) Of course the alterations in the temperature and pressure which have taken place in the lower regions of the atmosphere, obtained from observations at ground stations and during the course of the descent, must be taken into account, though these corrections are usually very small.

Since it seldom happens that there will be a meteorological station directly under the balloon, the temperature and pressure for this point must be obtained by interpolation from the observations at neighbouring stations. This is done most easily by drawing *weather charts* with isobars and isotherms for half-hourly or hourly intervals during the course of the ascent, providing that the observations at the meteorological stations are sufficiently frequent for this to be done.

After the known corrections have been applied to the balloon thermometers, the heights are used for the determination of the alteration of the temperature from the bottom of the atmosphere to various altitudes step by step, the *temperature gradient* per 100 metres usually being taken as the unit.

The temperature decrease in ° C. is divided by the corresponding difference in level in hectometers. This process gives, of course, only the average change, and none of the *characteristics of the single strata.*

For this latter purpose the temperature data with regard to the corresponding stratum must be taken—the thickness of the

strata being taken as 100, 250, 500, or 1000 m., as may be most expedient—and mean values taken, so that we obtain a series of points at different heights between which the temperature gradient may be taken as typical for that particular stratum. Besides the mechanical classification of the strata according to equidistant heights, those strata should be examined in which special conditions have been found to prevail, especially phenomena such as a temperature inversion, passage through a cloud, striking alterations in the humidity, direction of the wind, etc., and the temperature gradient for each determined.

If the ventilated psychrometer is employed, Sprung's formula (see Chapter I., § 7, and II., § 5) must be used to obtain the *tension of aqueous vapour* and the *relative humidity*, otherwise the ordinary tables may be used.

The alteration of the tension per 100 m. difference in height should also be determined. The calculation of the specific humidity and its alteration with the height will frequently enable much to be learnt regarding the condition of the masses of air present in the separate strata.

If the points over which the balloon has passed, as entered on the map, are joined with one another by a series of straight lines, we get the direction of motion of the balloon for the corresponding heights and times, and if we divide the distance between two consecutive points (in metres) by the time taken to pass between them (in secs.), we obtain the horizontal velocity of the balloon in m. per sec. for the mean height between these two points. Since the paths and velocities of the balloon represent the directions and velocities of the air currents, we can determine these for a series of different layers. We must be careful not to take the points too near to one another for the purpose of the calculation, unless, indeed, they have been very accurately determined, as it is easy to get values for the *direction* and *velocity* which are not the real values but are due to calculations with uncertain numbers. For larger distances the error will be much smaller, even though the observations were equally uncertain.

(*b*) **Graphical representation.**—In order to obtain a general idea of the weather conditions half-hourly or hourly, *weather charts* are very desirable; on these should be shown the isobars, isotherms, details as to clouds, rainfall, and winds derived from observations at various meteorological stations, as well as from those taken in the balloon. Frequently it is convenient also, especially for the simultaneous ascents, to draw a chart showing isobars, isothermals, and wind directions, at a height of, say, 5000 m. While these charts give the horizontal distribution of the physical conditions on the surface and at the chosen altitude, diagrams show-

ing the vertical distribution of temperature, etc., as derived from the balloon observations, are also useful. It is convenient also for many purposes to take as abscissæ in a rectangular co-ordinate system the projection of the path of flight on the earth's surface, which fixes the direction and the alteration of direction of flight developed so as to give the distances travelled from the starting-point as abscissæ, while the corresponding values of the pressure, height, temperature, absolute and relative humidities, cloud density, and so on, are taken as ordinates, the respective points being connected by curves. The abscissæ may all be measured from a common line, or from different parallel lines, for each single element considered. Under the lowest axis of abscissæ the distances must be written, and the corresponding times taken to cover these distances; between these numbers room may be made for the velocities of the balloon between each pair of fixed points. If we now write against the height curve the special observations (sunshine, clouds, precipitation, etc.) by signs, we obtain immediately the various elements at a given time or moment written vertically above one another. The scales chosen for the ordinates and abscissæ must naturally depend on the distances, heights, and amplitudes.

The time may be taken as the abscissa, and the elements, as before, as ordinates; the alteration of the direction of motion may be shown by corresponding arrows placed along the abscissa axis.

It is often advisable to proceed in quite a different manner, taking the heights as ordinates and the single elements as abscissæ, and again to connect the various corresponding points by curves; in this way we can see most easily how the various elements alter with the height.

In the temperature curve, especially, we detect from its various irregularities, the presence of temperature inversions, isothermal layers, and more or less rapid decreases with the height. If we take as unit of length for the ordinates 100 m., and for the abscissæ 1° C., the adiabatic alteration of temperature is given, for dry air, by a line inclined at 45° to the co-ordinate axes.

The method of representing graphically the elements must be chosen according to the purpose for which it is required; in general it serves for demonstration and for interpolation.

§ 8. DERIVATION AND CLASSIFICATION OF RESULTS.

The *mean values* of the temperature, temperature gradient absolute, relative, and specific humidities, direction of wind, velocity of wind, etc., at the different heights are finally tabu-

lated in one *table*, in order to make clear at a glance characteristic or exceptional peculiarities, which may then be further investigated in detail, and also in order to render more easy the comparison of the results with those obtained in other ascents.

In long voyages it is instructive to form a table showing the hourly variations of the elements in order to obtain the *daily period*. For several simultaneous ascents from different places the distribution of pressure and clouds near the ground must be taken into account, as well as the differences in a horizontal direction of the various physical conditions in the separate strata. Numerous ascents distributed over the whole year enable the *yearly variations* and differences in the vertical conditions to be investigated. Finally *classifications* according to the character of the clouds, distribution of pressure (cyclone or anticyclone), or other similar characteristics, are often of the greatest use. At the very least the mean temperature gradient (per 100 m.) in the separate strata must be determined for every ascent, and also the corresponding state of humidity of the air, cloud formations, and movements of the atmosphere.

§ 9. OBSERVATIONS WITH CAPTIVE BALLOONS, BALLONS SONDES, AND KITE ASCENTS.

The above relates principally to the results of manned balloon ascents. A great deal of what has been said, especially with regard to the computation and classification of the observations, applies equally well to records obtained with recording instruments alone, in unmanned ascents. Unmanned captive balloons, *ballons sondes*, and kites must be provided with recording instruments, in the construction and testing of which the greatest precautions have been taken, in order that the results obtained by their aid may be of a value equal to those obtained in manned ascents; they should only be employed by those who have received a thorough instruction in the use of the instruments from a specially qualified instructor.

CHAPTER IV.

TECHNIQUE OF BALLOONING.

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§ 1. SPECIFICATIONS.

THE specifications are necessarily based on the purpose for which the balloon is required. We must distinguish between air-ships, free balloons, captive balloons, parachute balloons, registering balloons or *ballons sondes*, pilot balloons, and hot-air balloons or "Montgolfiers." The gas to be used for inflating the balloon, the shape, size, and lifting power required must be stated.

1. **The gas** (*cf.* Chapter I).—The only gases which need be considered are hydrogen, with a lifting power of 1·1 kg. per cb. m., and coal gas, with a lifting power, which may be taken as 0·7 kg. per cb. m.

If the balloon is to be sent up from any fixed place, it is advisable to determine the specific gravity (s) of the gas manufactured there, and to calculate from this the lifting power (A) per cb. m.

1 cb. m. air weighs 1·293 kg.,

whence

$$A = 1{\cdot}293\,(1 - s). \tag{1}$$

In all uncertain cases it is safest to take for the specific lifting power

1·0 kg. per cb. m. for impure hydrogen.
0·65 ,, ,, heavy coal gas.

2. **The shape.**—The most useful shape is the spherical.

$$\text{Contents (capacity)} = V = \tfrac{4}{3}\pi r^3.$$
$$\text{Area of surface} = O = 4\pi r^2 = \pi D^2.$$

The best form for the tensions in the covering and net is, according to Lauriol, that taken up by the spherical

balloon, when supporting a weight in the air (*cf.* "Sur les Tensions des Enveloppes et des Filets," *R. de l'Aé.*, 1889-90).

Air-ships and balloons of special designs have almost invariably the shapes of volumes of rotation; the necessary calculations may be most easily carried out by the use of Guldin's rule.

The cubical contents of a volume of rotation, formed by the rotation of a surface about an axis, are equal to the area of the surface multiplied by the length of the path traversed by the centre of gravity of the surface in a complete revolution.

The area of a surface of rotation formed by the rotation of a line about an axis is equal to the length of the line tracing out the surface, multiplied by the length of path traversed by the centre of gravity of the line in its complete revolution.

Position of the centre of gravity for some common lines and surfaces:

1. Arc of a circle $\quad MS = \frac{rs}{b}$.
2. Semicircle $\quad MS = \frac{2r}{\pi} = 0{\cdot}6366r$.
3. Segment of a circle $\quad MS = \frac{s^3}{12P}$.
4. Surface of hemisphere $\quad MS = \frac{4r}{3\pi} = 0{\cdot}4244r$.
5. Triangular surface $\quad M'S = \frac{1}{3}T$,

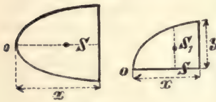

FIG. 12.

where M is the centre of the circle, r its radius, s = chord of arc, S = centre of gravity, b = arc of circle, M′ = middle point of the base of the triangle, T = the length of the line joining M′ to the apex, P = surface of segment.

6. Surfaces of segments of a parabola (see fig. 12).

$$OS = \tfrac{3}{5}x,$$
$$SS' = \tfrac{3}{8}y.$$

(*Cf. Z. f. L.*, 1884, p. 274; v. Brandis and Lindner, "*Übersichtstabelle des Gewichtsverhältnisse verschiedener Ballonformen.*" *R. d. l'Aé.*, 1894; Voyer, *Les cones sphériques et leur application à la construction des ballons allongés.* Lauriol, *Sur la forme des aérostats.*)

3. **Size and lifting power.**—These two quantities are mutually related to one another; they depend on the weight of the balloon material, the amount of ballast carried, and upon the height or duration of the proposed ascent.

The weight of the balloon material, if known, is easily

allowed for; if not known it must be determined in the laboratory.

The strength, and hence the weight per square metre of the balloon material required, increases with the volume V of the balloon (*cf.* § 5).

In air-ships the various portions of the construction must be treated separately; it is impossible to lay down any general rules.

The weight to be carried consists of the passengers, the car and its fittings, the instruments, and sundry other adjuncts.

The weight (G) which a balloon of volume (V) can raise to a given height is found from the formula

$$G = \frac{V.A}{n}, \tag{2}$$

where A = lifting power of the gas per cb. m.

$n = \frac{p}{p'}$ = the pressure on the earth's surface divided by the pressure at the maximum height to be attained.

It is convenient in the calculations to take the pressure on the earth's surface at 0° C. = 760 mm. mercury. n is given by

$$n = \frac{V.A}{G}, \tag{3}$$

and may be termed the height factor (Höhenzahl).

The size of a balloon which, unloaded, should reach a certain height determined by n, may be calculated, when the weight per sq. metre (m. kg.) of the material of the balloon is known, from the formulæ:

$$V = \tfrac{4}{3}\pi r^3$$

and

$$G = 4\pi r^2 m,$$

which, substituted in equation (2), give

$$4\pi r^2 m = \frac{\frac{4}{3}\pi r^3 A}{n},$$

whence

$$r = \frac{3mn}{A}; \tag{4}$$

$$V = \frac{36\pi m^3 n^3}{A^3}. \tag{5}$$

This last formula, found by P. Renard, is known as the *law of the three cubes.*

From this formula n can be calculated, when the other quantities entering into the formula are known.

$$n = \sqrt[3]{\frac{A\ \overline{V}}{m 36\pi}}. \tag{6}$$

If this value is substituted in the equation for the normal height

$$h_0 = 18400 \log n$$

we get

$$h_0 = 18400 \log \frac{A}{m} \sqrt[3]{\frac{V}{36\pi}}, \tag{7}$$

which may be also written

$$h_0 = 18400 \log \frac{A}{\sqrt[3]{36\pi}} + \frac{1}{3} 18400 \log \frac{V}{m^3}. \tag{8}$$

Taking hydrogen, and setting $A = 1 \cdot 1$

$$h_{0H} = -11833 + 6133 \log \frac{V}{m^3}, \tag{9}^*$$

or taking coal gas, for which $A = 0 \cdot 7$

$$h_{0G} = -15445 + 6133 \log \frac{V}{m^3}. \tag{10}$$

The first term of each expression is constant, showing that a balloon filled with hydrogen should reach a height greater by $15445 - 11833 = 3612$ m. than the same balloon filled with coal gas.

The second part of the expression shows that the normal height reached depends only on the relation $\frac{V}{m^3}$. Renard calls this the *characteristic of the balloon.*

A loaded balloon will not attain such a great normal height, and will have a different height factor n_0. Suppose the additional weight carried $= g$ kg. The total weight carried $= Om + g$.

The normal heights reached by balloons of the same size decrease with the weight of the balloon. If $\frac{1}{n}$ is the relative pressure in the position of equilibrium of an unloaded balloon, and $\frac{1}{n_0}$ the same for the loaded balloon,

$$\frac{\left(\frac{1}{n_0}\right)}{Om + g} = \frac{\left(\frac{1}{n}\right)}{Om}$$

or

$$n_0(Om + g) = n.Om,$$

* The numbers are slightly different if other values for the lifting power of the gas are used. If A for hydrogen is taken as 1·122 kg., the first constant is −11675. If A for coal gas is taken as 0·73 kg., the difference in heights which similar balloons filled with the two gases should reach works out to be 3300 m.

whence

$$n_0 = \frac{n}{\frac{g}{0m}+1}, \tag{11}$$

substituting this value in the height formula we get, for a loaded balloon

$$h_0 = 18400 \log \left(\frac{n}{\frac{g}{0m}+1} \right). \tag{12}$$

The *height attainable* is therefore dependent on the volume of the balloon, on the lifting power of the gas, and on the total weight carried by the balloon. In this calculation any influence of heat or moisture on the air and gas has been disregarded.

We define as the *normal height* (h_0) of a balloon, that height which it would attain if the temperatures of the air and gas were throughout 0° C.

For the calculation of normal heights, *cf.* Table XV.

The *duration of the flight* of a balloon of volume V is determined by the alterations which take place in the value of the ratio $\frac{A}{G}$ with time.

The lifting power or buoyancy A decreases continuously in consequence of diffusion (*cf.* J. Violle, *Lehrbuch der Physik*, II. 4). A material should be chosen which shows, when tested in the laboratory, the least amount of diffusion in a given time.

It is useless to attempt to prevent this decrease of lifting power, which is also brought about by various other causes, such as (*a*) the pressure of the gas on the material; (*b*) the expansion of the material; (*c*) the balloon itself not being perfectly gas-tight; and (*d*) the loss of gas through the heating and consequent expansion of the gas.

In order to overcome the loss of lifting power due to the escape of gas and other causes, a suitable supply of ballast in the form of dry sand, water, or water mixed with glycerine, is invariably carried. By throwing out ballast, the relation $\frac{A}{G}$ may be kept nearly constant as long as there is sufficient ballast left.

Ballast is also used to compensate for disturbances in the ascent (brake ballast), due to the deposition of moisture on the balloon, and to assist in the landing operations (landing ballast).

The increase of weight due to the deposition of moisture on the balloon depends on the material of which the balloon is made; it can only be estimated for any particular case.

Josselin (*L'Aé.*, 1901) has determined empirically the following

values for varnished balloon material, using for the purpose a specially constructed dynamometer :—

Form of condensation.	Weight per square decimetre in gm.		Weight per square metre in gm.		Weight per 500 sq. m. in kg.		Remark concerning the maximum value.
	Min.	Max.	Min.	Max.	Min.	Max.	
Dew (light)	0·15	0·5	15	50	7·5	25	
Dew (heavy)	0·8	2·4	80	240	40	120	rime
Rain . .	2	2·9	200	290	100	145	
Heavy rain	2·54	3·6	254	360	127	180	
Storm rain	3·9	4·8	390	480	195	240	wind
Snow . .	8	11·6	800	1160	400	580	

The calculation of the amount of *brake ballast* (x) needed may be made with the help of the formula :

$$(13) \qquad x = a\frac{A.V}{s}(\overline{\Delta t} - \underline{\Delta t}) = a\frac{A.V}{s}\left[[\overline{t'} - \overline{t}] - [\underline{t'} - \underline{t}]\right]$$

$$= a\frac{A.V}{s}\left[[\overline{t'} - \underline{t'}] - [\overline{t} - \underline{t}]\right]$$

where $A.V$ = the buoyancy of the balloon in kg.,

and $\frac{A.V}{s}$ = the weight of air displaced by the full balloon.

$\overline{\Delta t}$ = temperature difference at the maximum height.
$\underline{\Delta t}$ = " " on the earth's surface.
$\overline{t}$ and $\underline{t}$ = temperatures of air at upper and lower points.
$\overline{t'}$ and $\underline{t'}$ = " of gas " "

It is not possible to calculate the *amount of ballast required for landing.* The quantity depends on the degree of steadiness required, and on the skill of the conductor.

(*Cf.* Table XVI., "Relations of size and lifting power of different spherical balloons.")

§ 2. ESTIMATES.

In establishing a balloon depôt, the following equipment, fittings, etc., are necessary :—

1. **The workshop.** — A specially arranged workshop, with separate building-hall or other suitable large room (station hall, market hall, gymnasium, etc.).

2. **The fittings.**—(*a*) *The laboratory.*—Chemical balance and weights, tearing machine for balloon material and net strings, testing machine with dynamometer, thread counters, calipers, gas balance or Bunsen's apparatus for measuring the specific gravity of a gas.

(*b*) *The benches.*—Lamp, table for cutting out, sewing-machine, net-knitting machine, fan, rough balance, drawing materials. In a complete equipment all the joiner's tools necessary to construct the various balloon parts should be obtained. Joiner's bench, wood-lathe, metal-lathe, drilling-machines, and other tools; apparatus for varnish-making.

3. **The balloon materials.**—Balloon fabric, raw or rubbered; linseed varnish, net ropes and various other cords, tow, a hoop, valve, basket, wooden pins.

4. **The balloon accessories.**—Coverings, sandbags, gas hose and sockets, anchor.

5. **The balloon stores.** — Packing-sheets, sandbags, guide-ropes, anchoring arrangements, maps and instruments; for airships also motors and propellers.

6. **Workmen.**—Cutter-out, worker of sewing-machine, net-maker (sailor), basketmaker, mechanic, cabinetmaker, turner, metalworker, locksmith.

7. **Expenses connected with the ascent.**—Balloon inflation, cost of gas, workmen's remuneration, of journeys to and from the filling-place, transport of balloon and return journey, repairs, upkeep and storage expenses.

8. **Reserve fund for emergencies.**

9. **Liquidation of the capital expenditure.**

§ 3. MATERIALS.

A. **Fabrics.**—Silk, cotton (calico), linen.

Requirements.—A tight-woven fabric, linen or diagonal woven; uniform strong thread, with approximately the same number of threads in warp and woof, unbleached, and without dressing or finish. In case a coloured material is required, the chemicals to be used in dying it must be specified. Light weight and great strength are essential; the latter must be tested in a tearing-machine in both warp and woof, strips 5 cm. broad and 18 cm.

long being usually employed for testing purposes (*cf.* "Strength of balloon covering").

WEIGHT OF VARIOUS RAW FABRICS.

1. *For free and captive balloons.*

The finest German cotton (percale) weighs	75–85 gm.	per sq. m.
,, French ,, ,,	130	,,
,, Russian ,, ,,	115	,,
White silk (Balloon "Meteor") ,,	69	,,
,, (Russian military balloons) ,,	86	,,
Ponghèe silk (French military balloons)	80–96	,,

2. *For registering balloons.*

French (L'Aérophile No. 3) weighs	40	,,
Russian . . . ,,	56	,,

B. **Goldbeaters' skins.**—*Specification.*—The pieces must be free from small holes (due to worms), and must be well greased; the strength must be tested as above. Size of the skins 90 × 27 cm. A square metre of the single skin weighs 12·5 gm.

Goldbeaters' skins.

2	layers	in thickness,	uncoloured,	weigh	25 gm. per sq. m.
5	,,	,,	,,	,,	75 ,,
6	,,	,,	,,	,,	108 ,,
5	,,	,,	coloured,	,,	115 ,,
6	,,	,,	,,	,,	131 ,,
8	,,	,,	,,	,,	213 ,,

C. **Paper.**—Must be light, strong, and soft. Japanese papers (from the inner bark of the "Wickströmia Canescens," Japanese: *gampi*, *Edgeworthia papyrifera*: Japanese, *mitsu-mata* or *isuiko*, and *Broussonetia papyrifera*; Japanese, *kodsu*), best fulfil these conditions, and form the lightest possible balloon material for sizes up to 400 cb. m. The sheets are usually small, but can be procured 1·8 m. square (*cf.* Marten's "Untersuchungen japanischen Papiers," *Mitt. d. Kgl. techn. Versuchsstation*, Berlin, 1888). Weight (according to kind of paper) 6·5 to 85 gm. per sq. m.

D. **Rubber.**—Suitable only for small balloons up to 5 cb. m. contents. Only pure natural rubber, free from defects, and very soft and elastic, may be used.

§ 4. METHODS OF MAKING THE BALLOON MATERIAL GAS-TIGHT.

A. **Linseed oil varnish.**—*Preparation*, according to Arnoul, of St Quen. For the first coat a thin varnish should be used,

to fill up the pores of the material: 100 kg. linseed oil, 4 kg. litharge, 1 kg. umber, heated for six to seven hours at a temperature of from 150° to 200° C., being kept constantly stirred. After a few days the clear varnish is drawn off. For further coats a thicker varnish should be employed: viz., pure linseed oil, heated to 260° to 270° C. until it becomes sufficiently thick, care being taken that it does not take fire: preserve under a layer of water.

To prevent the parts of a varnished balloon sticking together, coat with a shellac solution, or a thin layer of olive oil, as soon as the varnish has become thoroughly oxidised. For balloons such as those used for advertising purposes, which are not required to last long, bronze or aluminium powder may be rubbed on with cotton waste. This soon turns green or grey owing to oxidation. The addition of rubber makes the varnish sticky; hard wax or gum lac makes it brittle.

Advantages of linseed oil varnish.—Cheapness; material easily made tight by applying it with a sponge or strips of flannel; great tightness.

Disadvantages.—Stickiness, especially at high temperatures, constant inspection necessary during storage; possibility of spontaneous combustion after being freshly varnished, if not kept in a well-ventilated place; a very slow process of making a balloon air-tight.

B. **Caoutchouc.**—Pure natural rubber dissolved in benzene is applied in a thin even sheet over the material and is then vulcanised.

Advantages of the vulcanised rubber material.—Absence of stickiness at all temperatures; the material remains soft and pliable.

Disadvantages.—The rubber decomposes under the influence of violet and ultra-violet rays, which must be protected against by painting the outer layer of material yellow; only really tight when several layers of material are used; expensive.

C. **Ballonin.**—A preparation of benzene and gutta-percha. Not sufficiently tight for most purposes.

D. **Conjaku.**—A Japanese vegetable material in the form of a powder soluble in warm water. Also not sufficiently air-tight.

E. **Chromium glue.**—Gelatine, to which a solution of potassium chromate in warm water has been added. During the process of varnishing daylight must be excluded or the mixture is rendered insoluble. Not very tight.

F. **Pegamoid.**—A patent material, suitable for varnishing the deck coverings of air-ships (*cf.* "Zeppelin's Air-ship," *I. A. M.*, 1902).

Weight of Various Gas-Tight Balloon Materials.

Finest silk, with three coats of varnish (Balloon "Meteor"), . . .	75	gm. per sq. m.
French ponghée silk, five coats of varnish, for small balloons, . .	220	,,
French ponghée silk, five coats of varnish, for large military balloons over 200 cb. m., ...	268	,,
Calico, with four coats of varnish, .	225	,,
,, ,, one coat of rubber, vulcanised, . . .	180	,,
,, of double diagonal woven material with vulcanised rubber between the layers, . . .	265–280	,,
,, double thickness, with vulcanised rubber between the layers and an outer sheet of rubber, .	310	,,
Pegamoid material for balloons, . .	120–140	,,

Weight of Balloon Fabrics, including Seams.

French ponghée silk, unvarnished,	weighs	96	gm. per sq. m.
,, ,, ,, with four coats of varnish and oiled, . . .	,,	333	,,
Calico, double, with vulcanised rubber layer between, and an outer sheet of rubber, . .	,,	390	,,

Weight of Gas-Tight Material of Certain Historical Balloons.

P. Haenlein's navigable balloon, 1872, ...	weighed	306	gm. per sq. m.
Dupuy de Lôme's navigable balloon, 1872, of silk, with seven layers of rubber, . .	,,	340	,,
Giffard's large captive balloon, 1878, of muslin, rubber, strong linen, rubber, linen, vulcanised linen and muslin, .	,,	1330	,,
The German balloons "Humboldt" and "Phoenix," of rubbered double percale, . . .	,,	330	,,
Graf von Zeppelin's air-ship, of vulcanised rubbered cotton (including seams), . .	,,	150–170	,,

The registering balloon "Cirrus II." of rubbered silk, . .	weighed	97 gm.	per sq. m.
The registering balloon "Langenburg," of rubbered silk, .	,,	120	,,
The registering balloon "L'Aérophile No. 3," of varnished silk, ...	,,	62	,,

(*Cf.* Dietel, "Herstellung der Ballonstoffe," *I. A. M.*, Jan. 1900.)

§ 5. STRENGTH OF THE BALLOON ENVELOPE.

The difference in the internal and external pressures on the balloon envelope increases with the height of the column of gas in the balloon, and is therefore greatest near the valve at the top of the balloon. The tension on the envelope is, on the contrary, greatest about 50° to 60° from the apex. The fact that a rapidly rising balloon having a large lifting capacity, with the neck too small or tied up, bursts in the neighbourhood of the valve, is due to the fact that the pressure exerted by the air above the balloon, against which it is moving, causes an irregular distribution of the tension in different parts of the balloon envelope.

The longer the tail (l), the greater is the upward pressure of the gas.

In any balloon the maximum pressure (Q) depends on the diameter (D), the length of the tail (l), and on the lift of the gas (A).

(14) $$Q = A(D + l) \text{ kg. per sq. m.}$$

In testing the strength, the pressure employed should be twice this amount, *i.e.*

$$P = 2Q.$$

It is convenient to give the pressure apparatus a circular area of 1 square metre, corresponding to a radius of 56·4 cm. In order to be able to calculate the tearing stress R directly from the reading of the manometer, Q atmospheres, and the sag b in cm., due to the pressure on the material, these should be measured when the material is just on the point of breaking, when, if the radius of the drum is a cm., we get for the tearing stress of the material per cm.

(15) $$R = \frac{Q(a^2 + b^2)}{4b},$$

where Q is expressed in kg. per sq. cm.

The maximum tension of the balloon fabric is calculated per linear metre, according to Renard's formula:

$$T = \frac{A(D + l)D}{4}, \tag{16}$$

which is based on the assumption that the maximum pressure Q is exerted throughout the whole volume.

The tearing stress of strips 5 cm. broad and 18 cm. long, as tested on the tearing machine, must bear to T a relation depending on the factor of safety (k) considered advisable.

$$R = \frac{k}{20}T.$$

For free balloons k is taken as between 15 and 20.

For captive balloons k is taken as 20 or more.

For registering balloons k is taken as 2.

For spherical balloons without tail the formula for the maximum tension can be written in the simple form:

$$T = \frac{AD^2}{4}. \tag{17}$$

Since $\frac{A}{4}$ for any particular gas is a constant, it follows that the tensile strength of the balloon material must increase as the square of the diameter.

The breaking stress (R) must necessarily be always greater than the maximum tension (T). We have, in fact,

$$\frac{T}{R} = \frac{1}{k} \text{ or } T = \frac{R}{k}.$$

If this value is substituted in the preceding equation, we get

$$\frac{R}{k} = \frac{AD^2}{4};$$

or

$$R = \frac{AD^2k}{4} \tag{18}$$

and

$$D = \sqrt{\frac{4R}{Ak}} = 2\sqrt{\frac{R}{Ak}}. \tag{19}$$

In consequence of the presence of the neck and tail, the following alterations must be made in the above expressions. For every kg. pressure per sq. m. of the neck,

$$\Delta T = \frac{D}{4} \text{ kg.}; \tag{20}$$

where ΔT is the extra maximum tension; and for every metre in length of the neck and tail

$$\Delta T = \frac{AD}{4} \text{ kg.} \tag{21}$$

Similarly the breaking tension permissible in the testing strips, 5 cm. broad, must be increased by an amount

$$\delta R = \frac{k}{20} \Delta T. \tag{22}$$

(*Cf.* Table XVII. for details concerning the strength of balloon envelopes.)

TEARING STRESSES OF STRIPS OF BALLOON MATERIALS 5 CM. BROAD.

Calico,	weight 78 gm. per sq. m.	along the warp 28·5 kg.	along the woof 29 kg.
,,	,, 84 ,,	,, 31	,, 33 ,,
,,	,, 83 ,,	,, 41	,, 33 ,,
,, (Russian),	,, 115 ,,	,, ...	,, 55 ,,
Silk, ,,	,, 86 ,,	,, ...	,, 62 ,,
Sea Island, ,,	,, 79 ,,	,, 35	,, 36 ,,

The warp is weakened by the to and fro movement of the shuttle.

§ 6. THE FIBRINES.

For nets, Russian or Italian hemp, China-grass, flax, cotton, and silk. For ropes also, Manila hemp and cocoanut fibres.

Test for strength, durability, weight, and for the increase of weight when moist.

Absolute strength.—The force with which the material resists tearing, when stretched in the direction of its length: it is proportional to the cross section of the material.

Breaking stress (K).—The force per sq. mm. cross section necessary to tear the material.

Breaking stress for silk, ...	K = 43·62 kg.
Breaking stress for China-grass, . . .	K = 16 ,,
Breaking stress for strong hemp, . .	K = 4·8 ,,
Breaking stress for thinner hemp, . .	K = 6·1 ,,

(According to Weissbach).

The strength will be reduced by tight twisting, tallowing, or tarring.

The breaking stress of the ropes employed must in every case be determined by reliable tests.

COMPARATIVE STRENGTHS OF SEWING MATERIALS (Espitallier).

Cotton, . . .	=	1
Hemp, . . .	=	1·3
China-grass, . .	=	1·5
Silk, . . .	=	1·8 to 1·9

BREAKING STRESSES OF ITALIAN HEMP ROPES (as tested by A. Riedinger at Augsburg).

Diameter.	Weight per m.	Breaking stress. per sq. mm.
mm.	gm.	kg.
3	10·3	60
4	15	90
5	21·5	110
6	32·5	300
7	44·4	400
8	55	670
9	75	720
10	84	850
11	90	1150
12	101	1550
13	127	1560
14	147	1600
15	160	1700
16	198	2300

Ropes made by hand proved in all cases to be stronger than those machine made. With ropes of small diameter the variations in the breaking force are considerable.

§ 7. USE OF METALS.

Thin metal plate has not found favour for forming the envelopes of balloons, though metal is used for the valves, ring, stretching apparatus, and for stiffening, while mountings and small details in the construction, such as eyes, hooks, screws, etc., are also made of metal. In newer forms of air-ships (Schwarz and Zeppelin) almost the whole body of the balloon is formed of a light lattice-work of metal ; steel cables are used for the suspension of the car (Santos Dumont). Steel wires and cables are also extensively used in connection with kites and captive balloons.

TENSILE STRENGTH OF DIFFERENT METALS PER SQ. MM.

Steel wire—piano wire—tinned,	About 173–220 kg.
,, English,	,, 70–93 ,,
Wrought iron,	,, 84 ,,
Iron,	,, 61–64 ,,
Copper,	,, 40–41 ,,
Brass,	,, 60–61 ,,
Aluminium (cold forged),	,, 27 ,,
Wolframinium,	,, 30 ,,
Aluminium—chromium alloy,	,, 45 ,,
Magnalium,	,, 29–45 ,,
	(According to composition.)
Nickel-aluminium,	About 40 kg.
Victoria aluminium (partinium)— wrought,	,, 15 ,,
Aluman,	,, 30 ,,
Aluminium bronze (10 per cent.), cast,	,, 65 ,,

(For relative weights, see Table V.)

For aeronautical work magnalium seems to be the most suitable alloy.

COMPOSITION AND PROPERTIES OF THE LIGHTER ALLOYS.

(According to particulars furnished by the manufacturers in Neuhausen (N), Lüdenscheidt-Eveking (W. Berg) (B), and by the Deutscher Magnalium-Gesellschaft (M)).

Wolframinium.—Tungstan and aluminium with traces of copper and zinc (German patent No. 82,819), easily milled and drawn; can be used as sheets, tubes, wires, angle pieces. The material of D. Schwarz and Gf. Zeppelin's air-ships. Of great flexibility and expansibility. Sp. gr. 3·0 (B).

Chromaluminium.—Principally consisting of chromium and aluminium (German patent No. 90,723). Sp. gr. 2·9 (B).

Magnalium.—Magnesium and aluminium; can be melted, cast, milled, wrought, compressed, welded, and soldered. Sp. gr. 2·4–2·57 (M).

Argentalium.—Silver and aluminium (German patent No. 132,612). Sp. gr. 2·9 (B).

Nickel-aluminium.—Sp. gr. 2·9 (B).

Victoria-aluminium.—Copper and zinc with aluminium, suitable for castings. Sp. gr. 2·8–3 (B).

Aluman.—10 per cent. zinc, 2 per cent. copper, 88 per cent. aluminium, can be wrought and milled. Sp. gr. 2·9 (N).

Nickel-steel.—With 12 per cent. nickel. Used by M. Jullist, the constructor of the Lebaudy Air-ship. Tensile strength about 100 kg. per sq. mm.

WEIGHTS OF MAGNALIUM SHEET, TUBE, AND WIRE (prepared by the German Magnalium-Gesellschaft of Berlin).

Magnalium Sheet.		Tube.									Wire.	
Thickness in mm.	Weight per sq. m. in kg.	Outer Diam. in mm.	Thickness in mm. 1	1·5	2	2·5	3	3·5	4	5	Diameter in mm.	Weight per m. in gm.
0·1	0·25	10	0·085	0·133	0·185	0·241	0·301	0·365	0·432	0·579	0·1	0·02
0·125	0·313	12	0·100	0·157	0·216	0·280	0·330	0·418	0·494	0·656	0·15	0·046
0·2	0·50	14	0·116	0·180	0·247	0·318	0·393	0·473	0·556	0·733	0·2	0·08
0·25	0·625	16	0·131	0·203	0·300	0·359	0·440	0·527	0·618	0·811	0·25	0·126
0·3	0·75	18	0·147	0·228	0·320	0·396	0·486	0·580	0·685	0·888	0·3	0·18
0·4	1·00	20	0·162	0·248	0·340	0·434	0·533	0·635	0·741	0·965	0·4	0·32
0·5	1·25	30	0·240	0·365	0·494	0·627	0·786	0·888	1·05	1·351	0·5	0·50
0·6	1·50	40	0·316	0·480	0·682	0·820	0·997	1·16	1·36	1·737	0·6	0·72
0·75	1·875	50	0·394	0·597	0·805	1·013	1·230	1·43	1·67	2·123	0·7	0·98
1	2·50	60	0·471	0·712	0·957	1·20	1·460	1·70	1·97	2·510	0·8	1·28
1·25	3·125	70	0·550	0·830	1·110	1·40	1·691	1·97	2·286	2·897	0·9	1·62
1·5	3·75	80	0·626	0·944	1·266	1·60	1·923	2·24	2·872	3·28	1·0	2·00
1·75	4·325	90	0·700	1·060	1·420	1·79	2·155	2·51	2·9	3·67	1·5	4·52
2	5·00	100	0·800	1·172	1·560	1·98	2·386	2·8	3·21	4·05	2·0	8·00
2·5	6·25										2·5	12·50
3	7·50										3	18·04
3·5	8·75										4	32·00
4	10·00										5	50·00
4·5	11·25										6	72 00
5	12·5										7	98·00
											8	125·00
											9	162·20
											10	200·00

CALCULATED BREAKING STRESSES OF STEEL CABLES WITH AN INTERNAL HEMP CORE.—Breaking stress of the steel wire used about 220 kg. per sq. mm. (Riedinger).

Breaking stress of the cable.	No. of wires.	Strength of wire mm.	Diameter of cable mm.	Weight per 100 m. in kg.
250	42	0·2	1·9	1·25
360	42	0·25	2·3	2·0
500	35	0·3	2·5	2·3
660	24	0·45	3·3	3·4
750	108	0·22	3·5	3·9
950	114	0·25	4	5·1
1500	114	0·3	4·5	7·5
2000	114	0·32	4·9	10
2500	114	0·38	5·8	11·8
2750	114	0·4	6	13
3000	114	0·45	6·8	14·0
4500	114	0·5	7·5	20
4760	222	0·37	7·9	23·74

§ 8. THE USE OF DIFFERENT KINDS OF WOOD.

For valves and rings : ash or walnut ; for baskets : wicker (willow wands) and Spanish cane : selvages from fir or oak ; for crossbars : ash, walnut, beech ; for yards : rods of ash ; for stiffening : bamboo rods and strong Spanish cane, artificial tubes made from very thin wooden strips glued together ; for kites : fir, ash, and American poplar.

§ 9. THE CUTTING OUT OF THE MATERIAL.

(1) **Calculations.**—The amount of material necessary for the manufacture of a spherical balloon exceeds the area of surface of the sphere by 10 to 50 per cent., according to the method of cutting out employed.

The breadth of the material, after allowing 2 to 4 cm. for a broad seam and for overlapping, divided into the circumference of the balloon gives the number of balloon gores. In order to obtain the breadth of the gore at different latitudes the breadth of the gore at the equator must be multiplied by the following numbers:—

TABLE FOR CALCULATION OF SHAPE OF BALLOON GORE.

0° = 1·0000	24° = 0·9135	48° = 0·6691	72° = 0·3090
3° = 0·9986	27° = 0·8910	51° = 0·6293	75° = 0·2588
6° = 0·9945	30° = 0·8660	54° = 0·5878	78° = 0·2079
9° = 0·9877	33° = 0·8387	57° = 0·5446	81° = 0·1564
12° = 0·9781	36° = 0·8090	60° = 0·5000	84° = 0·1045
15° = 0·9659	39° = 0·7771	63° = 0·4540	87° = 0·05234
18° = 0·9511	42° = 0·7431	66° = 0·4067	
21° = 0·9336	45° = 0·7071	69° = 0·3584	

The breadth of the gore between any two parallels is found by transforming the circular measure of the angle between the parallels (subtending an angle α at the centre of the balloon) into metres according to the formula,

$$h = \frac{\pi r \alpha}{180} = 0{\cdot}017453\, r\alpha,$$

where h = the distance between the two gores, and

r = the radius of the balloon.

(2) **Graphical determination of a balloon pattern of any form.**—On a vertical diameter draw a half section of the balloon on the largest possible scale. Starting from one end, divide the curve into a large number of parts as nearly equal as possible. Drop perpendiculars from the points of division to the axis of revolution. The width of any gore is given by the distance between the perpendiculars, and the breadth at any point is found by multiplying the lengths of the perpendiculars by $2\pi = 6{\cdot}283$, and dividing the number so obtained by the number of segments which the balloon is to have.

(3) **Finsterwalder's method** (D.R.P. No. 125,058).—Finsterwalder has suggested a new method of cutting out the material, in which the balloon is considered as a spherical hexahedron. This method of cutting out effects a great saving of material (22 to 30 per cent.), and has the further advantage that the seams are fewer (45 to 65 per cent.) (*I. A. M.*, p. 155, 1902).

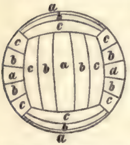

FIG. 13. — Finsterwalder's mode of cutting out.

The breadth of the material and circumference of the sphere must be used as the basis for the cutting out of the pattern. The length and form of the twelve-cornered segments of the regular hexahedron imagined inscribed in

the sphere are first determined, and from these the different forms of segments, which are to serve to fill the four-cornered segments of the spherical surface are deduced.

For details concerning other methods of division, using regular polyhedra of larger numbers of sides, applicable to the case of larger balloons, consult the appendix to the above patent.

§ 10. THE TAILOR WORK.

1. **The preparation of models** (*cf.* fig. 14).—The gores obtained as above, either by calculation or construction, are divided into two halves and are sketched on pasteboard. The models are cut out, care being taken to allow sufficient breadth for the seam and for the overlapping of material at the seam.

2. **The cutting out.**—Be as economical as possible in cutting out the material, and take care to avoid seams. Mark the material to correspond to the pattern in such a way that any puckering of the material in the sewing together may be detected and avoided. It is better, now that the manufacture of balloons can be carried out on a large scale, to cut all the sections simultaneously on a cutting machine.

3. **The needlework.** — Breadth of seams, 0·5 to 2 cm., according to the size of the balloon. Hem raw edges. In the case of rubber materials, fold the two edges into one another to give a flat surface and sew through them, afterwards smearing the thread-holes with rubber solution. Then stick pieces of the material over the seams with rubber solution. Moisten rubber materials when sewing. Sew the gores together in twos or threes first, afterwards several with one another. Test the strength of the thread and seams. Make the stitches 1 to 2 mm. apart.

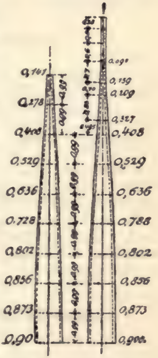

FIG. 14.—Pattern of balloon segment for a pear-shaped balloon of 1000 cb. m. capacity.

§ 11. VARNISHING.

Varnish the gores in turn, carefully making tight all seams. Varnish one-half of the envelope first, then, after allowing it to dry in a light airy place, but protected from the sun's rays, for some days, treat the other half in the same way.

Dry each half separately by hanging on a wheel-like framework, so that the fabric hangs around the wheel in the shape of a bell.

Proceed in the following manner:—(1) Use a thin varnish which penetrates the fabric, on one side, then turn the envelope. (2) Give a thin coating of varnish to the other side. (3) Give a thick coating of varnish to close all pores on the outside. (4) Give a thick coating to the inner side so as to close the pores completely. (5) When thoroughly dry, paint a thin coating of olive oil on the outside.

The most careful workmanship and very slow drying are essential conditions for the production of a good tight envelope, free from stickiness.

AMOUNT OF VARNISH NECESSARY.

The

1st coat	requires	1·5	times the weight	of the envelope	in	varnish.
2nd	,,	0·5	,,	,,	,,	,,
3rd	,,	0·3	,,	,,	,,	,,
4th	,,	0·15	,,	,,	,,	,,
5th	,,	0·1	,,	,,	,,	,,

The seams are taken into account in this table. The nature of different fabrics, and the care with which the varnishing is carried out, cause deviations from these figures to occur.

For drying, a space with clean floors, free from sand, must be used. The envelope should be blown out with air in order to accelerate the drying only in a case of necessity. Renew the air-filling frequently.

§ 12. MANUFACTURE OF BALLOONS FROM GOLD-BEATERS' SKINS.

1. **English method** (Howard Lane, 1887; English patent, No. 15,567).—Lay and fasten together the small skins on a spindle whose length is equal to the diameter of the balloon. The spindle is fixed in brackets, and is turned about its axis until a point on its surface has covered a distance equal to that of the circumference of the balloon. The number of turns necessary is given by the circumference of the balloon divided by that of the spindle.

2. **French method** (Lachambre, Paris).—Lay and fasten together the skins over a model balloon, tightly inflated with air. Hang the balloon so that it may be readily turned about its axis.

3. **Execution of the work.**—Oil the model. Soften the prepared gold-beaters' skins in water and lay on the pattern, cutting

off irregular edges with scissors. Lay the edges over one another and fasten together with isinglass. Put a second layer over the junction while the first is still moist, and so on up to three or four thicknesses. Glue over the whole bands of skin of five or six layers in thickness to form a network covering, which will act as a protection against accidental tearing of large sections. Above these place another three or four thicknesses. Strengthen the envelope at the two poles. In the English method, cover the surface with material during a whole revolution of the spindle, and when the whole circumference is ready and dry, carefully unroll the spindle.

In the French method, deflate the model balloon, at the same time inflating the goldbeaters' skin balloon.

§ 13. THE TAIL.

Object.—To lead in the gas, and to enable the gas to flow out when the pressure inside the balloon becomes greater than that outside.

Renard gives the following dimensions, deduced from experiments carried out in Chalais-Meudon :—

(*a*) For hydrogen balloons :

Smallest diameter, $d_H = 0{\cdot}008\ D^{\frac{3}{2}}$ metre.
Smallest length, $l_H = 4d_H$ metre.
Smallest cross section, $S_H = 0{\cdot}00005\ D^3$ sq. m.

(*b*) For coal gas balloons :

Smallest diameter, $d_G = 0{\cdot}01\ D^{\frac{3}{2}}$ metre.
Smallest length, $l_G = 4d_G$ metre.
Smallest cross section, $S_G = 0{\cdot}00008\ D^3$ sq. m.

The tail is sewn on as a cylindrical tube attached to a circular aperture in the envelope of the balloon, the material around the aperture being strengthened. The mouth is stiffened by a ring of wood, over which the eyes of the tail cord are fastened.

Tail valves (*cf.* § 14) are either bound or inserted into the mouth of the tail. They must open automatically as soon as the interior excess pressure becomes almost equal to the maximum pressure Q (*cf.* § 5).

§ 14. BALLOON VALVES.

We must distinguish between Manœuvring, Emptying, and Tail valves.

In free balloons, with a slit and tearing line, only a ma-

nœuvring valve is used; in captive balloons both emptying and tail valves are necessary.

The opening must be gas-tight, readily opened, and of convenient size.

The gas-tight opening in almost all the following types of valves is obtained by means of indiarubber plates and tubes.

(1) Pressure of sharp metal corners (Giffard, Yon), or rubber corners (Gross) on hollow rubber plates.

(2) Pressure of rubber rims against metal rims (Hervé), or against wooden rings with wooden channel (Moedebeck).

(3) Rubber membranes laid against metal surfaces (Graf v. Zeppelin).

(4) Window-like valve openings filled up by inflating rubber cushions lying against them (Renard's valve, fig. 15. A, manometer; B, cross tubes with valves; C, rubber).

Liquids, such as glycerine or Peru balsam, should not be used to make the valve gastight. The valve is kept closed by means of guiding pins, or by a suitable grouping of levers in combination with springs or rubber bands.

The springs must be all of the same strength, and so distributed that they produce a uniform pressure over the tightening surface of the valve. In order to find the necessary lifting power, all these springs must be taken into consideration, the sensitiveness of the packing, the weight of the separate parts of the valves and of the valve line, and the strength of the balloonist.

(Single screw valves, C. Lülleman; German patent No. 32,949, *Z. f. L.*, 1886, p. 33.)

Types of valves.—Plate valves, clap valves, tube valves, and membrane valves. The length of stroke in the case of a plate valve must be at least half the radius of the valve.

SIZE OF VALVE OPENINGS (Renard).

D = diameter of the balloon in metres.

Kind of balloon.	Manœuvring valve.		Emptying valve.	
	Smallest section.	Smallest diameter.	Smallest section.	Smallest diameter.
	sq. cm.	cm.	sq. cm.	cm.
Hydrogen, . .	$0{\cdot}0089\,D^{\frac{5}{2}}$	$1{\cdot}064\,D^{\frac{5}{4}}$	$0{\cdot}0178\,D^{\frac{5}{2}}$	$1{\cdot}504\,D^{\frac{5}{4}}$
Coal gas, . .	$0{\cdot}0218\,D^{\frac{5}{2}}$	$1{\cdot}668\,D^{\frac{5}{4}}$	$0{\cdot}0436\,D^{\frac{5}{2}}$	$2{\cdot}358\,D^{\frac{5}{4}}$

These figures are based on the supposition that the balloon is to be emptied in the first minute of $\frac{1}{30}$th of its contents in the case of the manœuvring valve, and of $\frac{1}{15}$th in the case of the emptying valve. A more exact theoretical deduction can be obtained from the formula given in Chapter I., A, § 11.

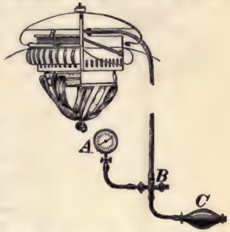

FIG. 15.—Renard's valve (half in section).

The tail valve should avert the outflow of gas and the entrance of air, due to the balloon swinging about and to the pressure of the wind, and should retard *diffusion*. In case the balloon is accidentally let free, it should automatically open, owing to the excess interior pressure. Usually plate or membrane valves, opening outwards, are employed.

§ 15. THE TEARING ARRANGEMENTS.

A simple button-holed slit on the upper hemisphere, preferably of triangular shape, of height $\frac{\pi r}{3}$ in the direction of the meridian. The inner surface is covered with a similarly shaped piece of

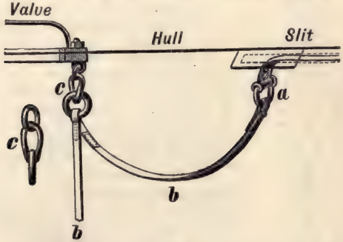

FIG. 16.—Tearing arrangements for a rubbered fabric balloon.

material, whose edges extend 15 cm. beyond the edge of the slit. At the upper point, which is strengthened by a square piece of material, is attached a wooden roller (a, see fig. 16), and a

rope to connect with the tearing line (*b*). The latter is distinguished from the valve line by being of a different colour, and is protected by looping through a ring fastened to a chain attached to the valve (*c*), and breaks away only when a pull of 60 or 70 kg. is exerted on it.

FIG. 17.—A net knot.

§ 16. THE ROPE-MAKER'S WORK.

The rope-maker's work includes attaching the car to the envelope of the balloon. In the case of captive balloons the attachment of the cable also comes under this heading. Besides these, the arrangements for manœuvring and anchoring must be included.

The car is attached to the envelope of the balloon:

(1) By nets (Charles, 1783) (*a*, diamond nets, *b*, square nets, *c*, meridian nets).

(2) Girth net (Meusnier, 1784).

(3) Net-coverings (Dupüy de Lôme, 1872).

(4) Girth suspension (v. Sigsfeld, 1890).

(5) Single line suspension (Riedinger, 1896).

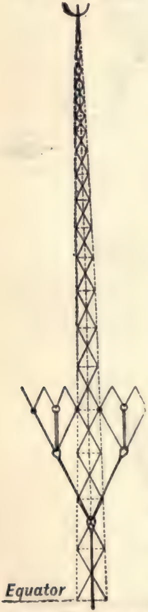

FIG. 18.—Segment of neck with goose's necks for suspending net.

1. **The net.**—*Object.*—External attachments to the balloon envelope are made by means of the net, which serves to distribute the pressure and pull over the whole surface of the balloon. Adjuncts to nets: valve ring, net cover, suspension net, hoop, holding net.

(*a*) **The diamond net.**—Accommodates itself to every alteration of form of the envelope of the balloon, but often stretches the material of the upper half of the balloon inside the meshes to a great extent, so facilitating the diffusion of the gas. The knots of the net destroy the tightness of the material by the extra pressure and friction, and catch in the material itself.

Construction of the diamond net.—A large number of small meshes have the advantage that they enable thinner string to be used, and consequently smaller knots, causing smaller tension and stretching of the material. Determine the number of meshes at the equator of the balloon. Make the length of a mesh twice its breadth. Multiply the breadth of the net by the numbers given in the table in §9. Construct a chain of meshes (*cf.* fig. 18). Mark in the meshes in the right proportions—breadth to length as 1 : 2. Measure the lengths of the sides for the purposes of knitting. At a suitable distance from the pole, where the meshes become too small, the relation between the diagonals of the rhomboid are altered in favour of the longer diagonal. The end strings are provided with loops

FIG. 19.—Ring suspension for goose's neck.

FIG. 20.—Bull's eye suspension for trail rope.

and strung on a rope rim, or wire rim. The latter must fit exactly around the valve rim. It is strapped on to this or is fastened in a special metal groove. In every case it must be immovably fixed to the valve rim. This upper part of the diamond-shaped net is called the "star" of the net from its shape.

Some 30° to 45° below the equator the suspension net is attached.

The strings of the goose's neck are drawn through bronze rings (*cf.* fig. 19), in order that all may be equally stretched when any alteration of the direction of pull occurs. On the lowest goose's neck the suspension gear cord is fastened by bull's eyes of beech-wood or bronze (*cf.* fig. 20). The guide rope is furnished with a spliced loop at the end to fasten it on to the ring.

Let n_0 = number of meshes around the equator;
n = number of meshes along any other meridian;
v = the ratio of the length to the breadth of a mesh usually $2:1=2$;
a = the angle which the particular radius of the sphere under consideration makes with the axis of the balloon;
e = the base of the natural logarithms $=2{\cdot}71828$;

then the number of meshes in the direction of the meridian within the angle a is given by

$$n=\frac{1}{2\pi\log e}\frac{n_0}{v}\log\cot\frac{a}{2}$$

$$=0{\cdot}36648\frac{n_0}{v}\log\cot\frac{a}{2};$$

and conversely $\log\cot\frac{a}{2}=2{\cdot}718\,v\frac{n}{n_0}$.

At the equator the breadth of a mesh $=\frac{2\pi r}{n_0}$

and the length $=v\frac{2\pi r}{n_0}$.

The dimensions of any mesh are found by multiplying by $\sin a$.

The weight of the net.—If M is the length of the meridian covered by the net, then the sum of all the meshes of the net

$$=\frac{2Mn_0}{v}\sqrt{1+v^2}. \tag{23}$$

This expression multiplied by the weight of the string per unit length gives the total weight of the covering net. A certain percentage, not yet determined, must be added for the knots. It is dependent on the diameter of the string and easy to determine by ascertaining the proportion of string used up per knot. With strings of different strengths the separate parts must be independently calculated and added together.

The tensions in the net.—The longitudinal tension in the parallel suspension strings L_0 is calculated from the total weight G (basket with contents and net) and the number of meshes of the net n_0 at the equator:

$$L_0=\frac{G}{n_0\sin a_0}, \tag{24}$$

where a_0 represents the angle corresponding to the meridian from which the suspending net is hung (about 120° to 135°).

The longitudinal tension L is given by

$$L = L_0 \frac{\sin \alpha}{\sin \alpha_0} \quad \frac{1}{v^2 e^{\mu(\alpha - \alpha_0)}} \quad \left(1 + \frac{1}{v^2}\right),$$

where μ is the coefficient of friction between the net and envelope.

The tension (S) in the sides of the meshes is:

$$S = \frac{\sqrt{1+v^2}}{2v} \text{ L.}$$

The pressure of the net against the covering.—Finsterwalder has developed the following formula for the normal pressure (N_s) of the net against the covering of the balloon:

$$N_s = \frac{G}{2\pi r^2} \quad \left(1 + \frac{1}{v^2}\right) \quad \frac{(\sin \alpha)^{\frac{1}{v^2}} - 1}{(\sin \alpha_0)^{\frac{1}{v^2}} + 1} \, e^{\mu(\alpha - \alpha_0)} \, \left(1 + \frac{1}{n^2}\right).$$

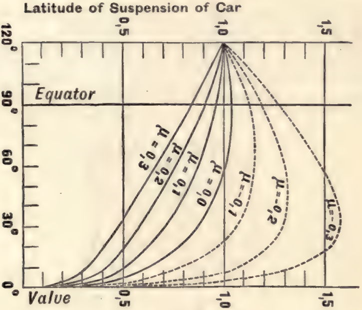

FIG. 21.

The increase by friction $= \mu d$N per mesh must be added to this.

The pressure of the net for different degrees of friction.—The value of the coefficient of friction μ between dry strings and a dry cotton covering is, according to the experiments carried out by Lieutenant Reitmeyer, at Finsterwalder's instigation, 0·20 to 0·23. For wet material μ is much greater and frequently exceeds unity. On account of the elasticity of the cords of the net and the flexibility and creasing of the balloon material, the effect of friction may be left out of consideration when the tension is great. Fig. 21 shows the relation L : L_0 for different

values of μ compared to the case when $\mu = 0$. The case when μ is negative shows the effect of friction on a wet net (*I. A. M.*, p. 1, 1901).

The knitting of the net.—For knitting the net we require a knitting bench (fig. 22), carrying one fixed and one movable

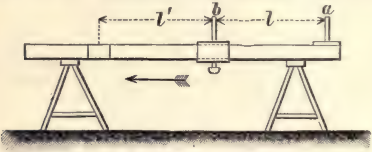

FIG. 22.—Net-making bench.

peg. It should be graduated in centimetres, so that the pegs may be quickly set at any desired distance apart. The net line should be wound on small pegs. The knitting is begun by winding loops over the fixed peg a, the small peg on which the cord is wound being carried each time round the second peg b, which is set at a distance of half the length of the first mesh l, from a. The small excess of length due to the winding round

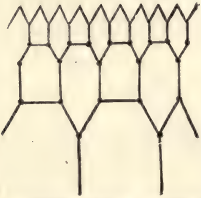

FIG. 23.—Suspending net. Giffard's system.

the peg must be taken into account. One less than the number of meshes desired must be knitted in the manner, the last mesh being formed by splicing the two ends. After completing the first row of meshes the movable peg is pushed on a distance equal to the length of the side of the next mesh, l', and the second row is knitted in a similar manner. If the knitting bench is not long enough, the completed meshes must be lifted off the bench and the last row placed over the peg a.

The suspending net is knitted in a similar manner.

The suspending net. — The suspending net is constructed directly on goose's necks and fastened to the net, either above the equator or at its equator. The lowest points are furnished with slips for fastening on the suspending ropes, which must

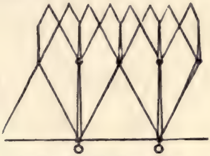

FIG. 24.—Suspending net.
Renard's system for French "normal balloons."

be of such a length that they reach to the lower side of the balloon car when the balloon is ascending. Shortening of the suspending net, Giffard's system (see fig. 23). *Cf.* G. Tissandier, *Le Grand Ballon captif à vapeur de H. Giffard*, Paris, 1878). Renard's system (*cf.* figs. 24 and 25).

Load on diamond-shaped nets.—The load corresponds to the

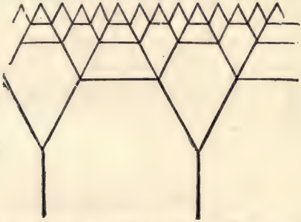

FIG. 25.—Suspending net. Renard's system.

total lifting power (N) diminished by the weight of the cover, tail, and valves. Owing to the cross tensions in the parallelograms, which are a maximum for an angle of 45° (when the ratio of 1 : 1 must be taken), the actual load must be multiplied by the coefficient 1·414. The table on p. 120 is taken from the report of the Committee for International Balloon Expeditions, Paris, 1900.

From this table we can calculate the strengths of the single

Net Tensions.

Contents of balloon.	Normal load.	Necessary increase for diamond nets.	Load for which net must be tested.	Breaking stress for net.	Load for which suspending net and car lines must be tested.	Breaking stress for car lines and suspending net.
V.	N.	P=1·414 N.	2 P.	10 P.	2 N.	10 N.
cb. m.	kg.	kg.	kg.	kg.	kg.	kg.
100	100	141·4	283	1,414	200	1,000
150	150	212·1	424	2,121	300	1,500
200	200	282·8	566	2,828	400	2,000
250	250	353·5	707	3,535	500	2,500
300	300	424·2	848	4,242	600	3,000
350	350	492·9	989	4,929	700	3,500
400	400	565·6	1131	5,656	800	4,000
500	450	636·3	1273	6,363	900	4,500
600	500	707·0	1414	7,070	1000	5,000
700	550	777·7	1555	7,777	1100	5,500
800	600	848·4	1697	8,484	1200	6,000
900	650	919·1	1838	9,191	1300	6,500
1000	700	989·8	1980	9,898	1400	7,000
1200	750	1060·5	2121	10,605	1500	7,500
1400	800	1131·2	2262	11,312	1600	8,000
1600	850	1201·9	2404	12,019	1700	8,500
1800	900	1276·6	2545	12,766	1800	9,000
2000	950	1343·3	2687	13,433	1900	9,500
2500	1000	1414·0	2828	14,140	2000	10,000

net and supporting cords, which must have together, in each row, a breaking stress $=10$ P.

If we divide the number of mesh cords, goose's neck cords, running out lines, and car lines into the figure in the fifth column, corresponding to the size of balloon employed, we obtain the necessary breaking tension of a single line (p).

The cross section (s) can be determined if we know the breaking modulus K of the corresponding material.

$$s=\frac{p}{K} \text{ in sq. mm.},$$

whence the diameter:

$$D=2\sqrt{\frac{p}{K\pi}}.$$

FIG. 26.—Meridian net.

Preservation of the net.—Protection against moisture and rot; paraffin, soaking or saturating with sodium acetate. Dry the net in the sun as soon as it has become thoroughly wet.

(*b*) **The square net.**—Does not increase in length in the direction of the parallels, presses the covering together very strongly in this direction when wet. Not to be recommended.

(*c*) **The meridian net.**—According to Finsterwalder's recommendations, only to be used when fitted with step-shaped cross strings. It is very simple and light, has everywhere the same

tension, and presses the covering equally at all points ; has very few knots. It has not yet been sufficiently tested in practice.

2. **The net covering.**—Consists of durable material with girth strengthening, covering the balloon down to where the suspending net is hung. Causes a regular distribution of pressure and friction on the balloon. Renders possible the protection of the balloon material against the precipitation of moisture and increases the tightness of the balloon.

Disadvantages.—Heavy weight and unequal action at different parts.

3. **Loop fastening.**—Loops sewn on, either at the height of the equator or somewhat lower. The suspension gear cord is fastened to rods or to the ends of rods which pass through these loops.

4. **Girth fastening.** — With strong and especially with rubbered diagonal balloon materials the supporting net may be fastened to a girth sewn and glued on to the balloon cover.

FIG. 27.—Girth fastening.

Advantage.—Keeps the suspending net rigidly in position. The cord may be fastened by the three-loop system (see fig. 27). (*Cf.* v. Parseval, "Drachenballon," *Z. f. L.*, 1896).

5. **Single line fastening.**—Only applicable to small signalling and rubber balloons ; small plate-shaped pieces of rubber of double thickness, fitted with rubber loops, are attached to the balloon at equal distances apart on the equator. A single cord is attached to each loop, these being fastened together at a suitable distance below the balloon.

§ 17. THE HOOP OR RING.

Fit thin sheets of wooden strips to a suitable hoop, mould and glue them together. As soon as the strength is sufficiently great, plane down to the desired cross section, and notch at the places where wooden pins for the suspending cords or car lines are to be fixed. Fasten the wooden pins with 15–20 cm. cord. The hoop must be oiled or polished and the fastening cords varnished.

In the case of hoops of metal tubing, the joint must be

strongly riveted with heavy pins; paint the hoop with red lead and wrap round with string. Over this fasten the pieces for the attachment of the ropes. Sizes of these cross pieces for supporting the car in the case of free balloons 10 cm. long by 3 cm. in diameter, for the suspension gear cord 7·5–9 cm. long, by 2–3 cm. in diameter.

§ 18. THE BASKET-MAKER'S WORK.

Willow and Spanish reed-work. Generally both are employed, the more durable cane being used for parts which require to be very firm and for those which are subject to the most wear. Willow cane is lighter. The upper edge must be stiffened by a strong tube of willow or cane, inside by a light bent metal tube, or by bamboo stiffening. Where it is desired to reduce the weight as much as possible the usual basket-work may be replaced by a crossed lattice work, with split Spanish reed in the remaining parts.

The basket-work under the floor must be continuous with the rest of the basket-work. The floor is protected by laying leather strips over it, and where the reed-work is subjected to friction by rubbing, it may be wrapped round with string. The floor is protected against sudden blows by cross pieces of wood, which serve at the same time to prevent it from bending under the weight carried.

Keepers are provided around the edge of the car to hang on the sand-bags, and to facilitate packing on landing; it is also advisable to provide catches for ropes at a small distance above the floor, both inside and outside the car.

The car ropes, usually eight in number, end in loops or small cross pieces.

The height of the basket work above the base must be at least 80 cm.

For greater convenience, the internal arrangements are usually furnished at the time of making, with a basket seat, serving at the same time for storage purposes, with compartments for oxygen bottles, etc. For long voyages Hervé constructed a car with double walls. The space between them was divided into different receptacles. In the case of large balloons (Nadar's "Le Géant," Andrée's "Ören") the cars were also provided with sleeping and living arrangements.

In a free balloon the ropes for attaching to the balloon are distributed uniformly round the hoop. A diagonal arrangement of the car ropes makes the attachment to the hoop stronger. In the case of captive balloons, and with balloons intended for tugging, a Cardanir fastening is better.

Cars or wicker-work cradles for air-ships (for military

purposes) are made in the same way as the lattice-work car, but out of bamboo or a strong light wood, with steel wire to serve as a stiffening for the diagonals, and copper wire as a binding material.

§ 19. LANDING ARRANGEMENTS.

1. **Tearing arrangements** (*cf.* § 15).—When used in combination with the trail rope of each anchor, the tearing arrangement makes the landing with proper handling quite safe, even in a strong wind, in consequence of the momentary emptying of the balloon.

In Germany and Austria the tearing arrangement is used without the anchor. The trail rope must be fastened underneath the tearing rope on the balloon-hoop.

2. **Anchor with friction or tearing brakes, trail rope, and emptying valve.**—The trail rope prevents a sudden jerk as the balloon leaves the ground, and similarly decreases the velocity of fall of the balloon.

The anchor needs more or less time, according to the nature of the ground, before the flukes are properly caught. The friction with which the anchor slides down the trail rope or anchor rope, or the "tearing brake" in which the anchor rope is put in tension only after a gradual tearing of several cords (becoming successively stronger and stronger), should give it a slow firm hold. The gas should then escape rapidly through the emptying valve.

The anchor.—Multiple armed friction and gripping anchors of relatively small weight, made in a solid manner out of the best material, should be employed.

Forms of anchors.

(1) Anchor with two prongs, with an anchor rod. Not very useful, since it can only grip with one prong.

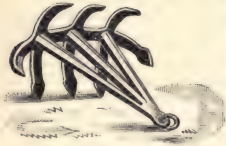

FIG. 28.—Anchor. Herve's system, Model B, 1884.

(2) Smith's patent anchor without a rod is more useful than the previous form, as it grips with two prongs.

(3) Four- to six-pronged anchors gripping with two or three prongs were formerly much used, but have been replaced by better forms.

(4) Six-pronged broad anchors (Hervé's System, 1884), Model A, grip with two prongs.

(5) Eight-pronged broad anchors (Hervé's System, 1884), Model B, grip with three prongs in the ground (fig. 28).

(6) Harrow anchors (de la Haye's System), constructed like a harrow, grip with several prongs.

(7) Chain anchors (fig. 29) of Renard's type combine the advantages of Hervé's and de la Haye's systems, and adapt themselves excellently to the form of the ground. Twenty pairs of anchors are bound together by links, giving forty prongs, twenty of which can grip the ground at once. Since the rods of the pairs of anchors are shorter near the end, the whole may be folded together so as to occupy very little space in the car. This is the best form of anchor in use, although somewhat difficult to construct.

(8) Sack-anchor (Jobert's System). A sack with sharp anchor prongs. Ought to diminish the velocity of the balloon by the friction caused in cutting up the soil, but is not a success in practice.

The *anchor flukes* or *prongs* may be of various shapes. The nature of the ground causes each form to have its advantages and drawbacks.

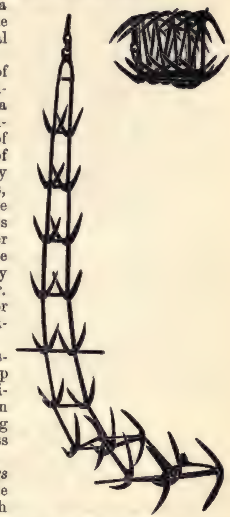

FIG. 29.—Chain anchor. Renard's system.

TABLE OF WEIGHTS OF ANCHORS (according to Cassé).

A balloon of 300 cb. m. contents requires an anchor 8–10 kg. in weight.

,,	600	,,	,,	,,	15–18	,,
,,	800	,,	,,	,,	18–20	,,
,,	1200	,,	,,	,,	20–25	,,
,,	3000	,,	,,	,,	40–45	,,

Anchor materials.—Wrought iron or cast steel.

Anchor line.—The breaking tension must be suitable for the size of balloon with which it is used.

If R is the head resistance when the velocity of the wind is v, $R = \zeta D^2 v^2$ in kilograms,
where D = diameter of the balloon
ζ = a coefficient, the value of which for spherical balloons = 0·025 according to Renard; or for types of balloons similar to the air-ship "La France" $\zeta = 0{\cdot}01685$ (Renard), or $\zeta = 0{\cdot}015$ (Canovetti). (*Cf.* § 6 and § 16.)

Trail ropes should be as rough as possible; they are often employed as anchor ropes, the anchor being allowed to slide down them by means of a rubber.

Rubbers.—Sliding constructions fastened to the rope offering a frictional resistance caused by closely pressed india-rubber pieces. At the lower end of the sliding piece there is an eye for the attachment of the anchor.

Construction of rubber.—Sivel, Penaud and others (*cf.* Moedebeck, *Handbuch der Luftschiffahrt*, p. 59; *Z. f. L.*, 1893, p. 211).

Tearing brakes.—Depend on the tearing of a number of bands, becoming stronger and stronger, before the anchor line can be put in tension. These strings are fixed in a loop of the anchor line in such a manner that they are pulled one after another. This is best accomplished by fastening two bronze discs in loops in the anchor line at a distance of about a metre apart. The discs are bored with a number of holes of different diameters, corresponding to those of the tearing strings, which are passed through them and held by suitable knots.

§ 20. THE WATER-ANCHOR.

In order to hold the balloon steady on water a driving anchor is used (*R. de l'Aé.*, vol. xv., Hervé, "Les ancres de cape").

1. **Sivel's sack-anchor** is an extremely useful form (1873).

It consists of a conical-shaped sack with a metal hoop at the opening, which serves to fasten the sack to the anchor line by a goose's neck connection. To weigh the anchor a second line is employed, fastened to the point of the cone or to the metal rim. The latter is better, because it allows the tension to be distributed between two ropes and causes the resistance to be introduced more gradually. To prevent the ropes twisting, and the anchor turning in the water, a turning plate (A) on ball bearings (B) is used (Hervé, *Émerillon d'antitorsion*).

In order to be able to use the second line as a manœuvring line, Hervé passed it over a pulley (D) after passing through the turning bit (A) (fig. 30).

Hervé recommends the use of a series of sack-anchors attached

to one another and of increasing size towards the balloon in order to prevent a too sudden shock. To prevent twisting, small rods must be fastened between each system of goose's necks.

The following are other forms of aeronautical driving anchors:

2. Hugh Bell's umbrella-shaped water-anchor (*R. de l'Aé.*, xv., 1900, p. 116).
3. Pagan's umbrella-chain (*R. de l'Aé.*, xv. p. 139).
4. Brissonet's disc-chain (*R. de l'Aé.*, xv. p. 141).
5. Tifernate's ladder-shaped anchor (*Saggio aeronautica*, 1819, p. 86, and *R. de l'Aé.*, xv. p. 135).

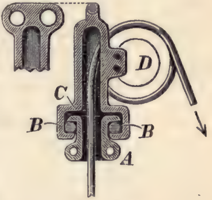

FIG 30.

According to Hervé, in a system of driving anchors the rearmost should be furnished with a ballast weight, so that it does not float upwards. At the same time it should be fastened to a buoy to limit the depth to which it can sink.

The balloon must be kept by means of a trail-rope at an approximately constant height above the surface of the water, so that the angle of drag with the driving anchor remains as constant as possible (*cf.* § 22, 2).

Diameters of Sack-anchors (Hervé).

Let F_B = greatest cross section of the balloon.
F_A = cross section of the anchor opening.
v = velocity of wind.
v_1 = velocity of drift.
ζ and μ = coefficients depending on the resistance offered by the particular shapes to air and water respectively.

The pressure on the balloon is:

$$R_B = F_B\,\zeta(v - v_1)^2,$$

while that on the anchor sack exerted by the water is:

$$R_A = F_A\,\mu v_1^2.$$

Since R_A must be $= R_B$, we get from these the equation

$$F_A = \frac{R_A}{\mu v_1^2},$$

whence the diameter d of the sack anchor is given by

$$d=2\sqrt{\frac{F_A}{\pi}}.$$

The coefficient of resistance of sea water, derived from its density as compared to that of the air $=\frac{1026}{1{\cdot}293}=793{\cdot}5$. The resistance of the air against a surface of 1 sq. m., moving with a velocity of 1 m. per sec. $=0{\cdot}080$ kg. The resistance of the water against a surface of the same size, moved with the same velocity $=793{\cdot}5\times0{\cdot}080=63{\cdot}48$ kg.

§ 21. TRAIL ROPES AND FLOATS.

I. **Trail ropes.**—These are used to enable a balloon to be kept for the longest possible length of time in stable equilibrium at a short distance above the ground or above water; for if the balloon tends to rise a little, part of the rope lying on the ground is lifted and the balloon is therefore weighted and sinks again; whereas, if it tends to fall, the balloon is lightened owing to more rope being on the ground.

Specifications for trail ropes.—(*a*) On land: sufficient weight in the lower parts to keep the balloon steady. The committee of the Paris voyages of 1900 required as the minimum weight $\frac{1}{50}$ that of the lift of the balloon. The surface must be smooth and the cross section small in order to reduce friction, which adversely affects the speed of travelling.

The ends should be fairly elastic to prevent wrapping round trees, telegraph poles, etc. (*cf. I. A. M.*, 1901, p. 34, Berson, Süring, Alexander).

In order to strengthen the rope it is wrapped with metal wires, or a wire rope is employed for the trailing portion.

The length must be sufficient for the size of balloon.

(*b*) On water: in addition to the above, it must float on water, and must not spoil by absorbing water.

Hervé, who first treated the subject from a scientific standpoint (*cf. Supplément de la R. de l'Aé.*, "Stabilisateurs statiques d'inclinaison," Paris, 1900) introduced the idea of the intensity (J) of the trailing rope to serve as a comparison for different specifications. He defined as the "intensity," the relation of the weight (g) to the length (l) for the homogeneous portion

$$J=g/l.$$

The specifications recommended, and in part tested by him, are the following:—

1. *Trail ropes for use on land.*—Cylindrical cable of metal and hemp interwoven. J = 3 to 5.

2. *Marine trail ropes.*—Cylindrical cable of metal wrapped with tarred tape, tallowed, and protected by a rubber covering. Cork shavings or bits of cork are put in the core of the cable in order that it may float. J = 8 to 12. In dangerous voyages several cables should be carried.

3. *Trailing ropes* for land and water (*stabilisateurs généraux*). A mean between the last two. J = 4 to 6.

II. **Floats.**—Cigar- or fish-shaped pieces of wood, which float easily, and offer little resistance to being drawn through the water, but, being weighted with lead, are difficult to lift out of the water. They serve to bind the balloon, as it were, to the surface of the water. J = 50 to 160.

Since the weight of the trail-rope is only very small compared to that of the floats, only very small differences in the height of the balloon can occur with their use—limited, in fact, by the stretching of the trail-rope.

The floats must conform to the wave movements of the water, otherwise a continual lightening and loading of the balloon will occur, causing the car to shake badly. This is accomplished by having series of floats. A simple form consisting of a long chain, the links of which were of wood having about fifteen movable limbs and weighing 600 kg. for a length of 5 metres, and for which J = 120, was tested by Hervé with good results in his Mediterranean voyage of 12th October 1901 (*I. A. M.*, p. 1, 1902).

§ 22. STEERING ARRANGEMENTS.

1. **Sails.**—Steering a balloon by utilising the wind necessarily causes a lessening of its velocity, just as the friction of trail ropes or floats reduces it. A balloon can, however, be steered by a suitable arrangement of sails (*cf. Z. f. L.*, 1895, p. 113. Andrée).

Andrée placed his sails between the balloon and the car; Rae used a sail attached to the hoop. A slanting position may be obtained by hooking the trail rope to different points on the hoop. A trail-rope of heavy hemp (J = 0·64) is used, in the middle a strong, and at the end a weak, cocoanut thread rope is used as sliding rope, J = 0·43 and 0·22. A deflection to one side up to 48° may be obtained.

2. **Driving anchors** (*v.* fig. 31).—These combine the functions of retarding and navigating the balloon, as soon as they are drawn through the water. The direction of pull must be at an angle α of approximately from 20° to 25°. The height of the balloon above the surface of the water must be regulated and kept constant by means of a trail-rope E. The driving-anchor

rope l must be fastened to the same point in the balloon rigging as the trail-rope E. The depth of immersion of the driving-anchor must be regulated by means of suitable floats.

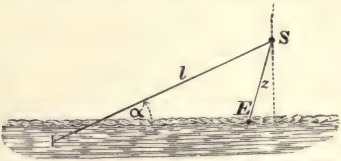

FIG. 31.—Method of attaching driving-anchors and floats.

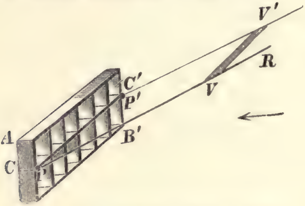

FIG. 32.—Hervé's cellular driving-anchor.

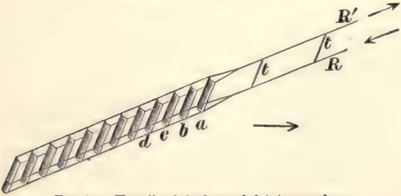

FIG. 33.—Hervé's plate-formed driving-anchor.

Hervé devised and tested the following constructions :—

(*a*) The cellular driving-anchor (fig. 32), (*déviateur lamellaire à minima*) is box-shaped and strong. It can be arranged, if not wanted for retarding purposes, so that the driving angle $=0°$, *i.e.* the water flows through it without dynamical action

on the walls, so that it does not need to be lightened during the journey. Maximum deviation during the trial, 40° (*I. A. M.*, 1902, 1).

(*b*) The plate-formed driving anchor (fig. 33) (*déviateur lamellaire à maxima*), formed of plates offering a great resistance; can be folded up and conveniently stored in the car. Allows a large driving angle. A trial trip gave 65° to 70° (*I. A. M.*, 1899, p. 60). (*Cf. R. de l'Aé.*, Supplément, 1900. Hervé, "Déviateurs lamellaires.")

§ 23. BALLOON ADJUNCTS.

These include ballast bags, packing arrangements, floor arrangements, gas hose, gas sockets, ventilators, and safety lamps.

1. **Ballast bags** are made of strong sail-cloth or ticking, of a cylindrical shape, 40 cm. deep and 25 cm. in diameter. At the upper end there are four hemmed holes for the ropes, which are drawn through them and spliced. The ropes are about 40 cm. long, and are joined together at the top by means of loops or knots, furnished with a bronze hook at the junction.

2. **Packing arrangements.** — Rectangular pieces of strong sail-cloth. The sizes must be calculated so that the envelope of the balloon can be packed into them. The pieces must be furnished with six straps, so that the packet may be conveniently tied up.

3. **Ground covers.**—Simple rectangular pieces of durable material, which can be laid on the ground to prevent the envelope of the balloon becoming soiled.

4. **Gas hose.**—A hose either varnished or made gas-tight by some other means. The diameter must be such that the gas delivery pipes can be inserted.

5. **Gas sockets.**—Cylinders of zinc strip, about 20 to 25 cm. long, with padded edges. They serve to connect the filling-hoses with one another and with the balloon. The diameters must be such that the filling-hose pipes will fit into them. If the balloon is to be filled simultaneously from several delivery pipes, a junction piece will be necessary in order to connect all the pipes to the hose leading to the balloon.

6. **Fans**, to clear out the envelope of a balloon after the journey, are made of wood and metal in special factories. Wooden fans are lighter to handle. In using, the fan is placed some little distance in front of the mouth, so that it sends a current of air into the balloon, thus driving out the enclosed gas.

7. **Safety lamps** are absolutely necessary for night work. The same forms are used as in mines. The gauze must be

perfect, and the lamps must be closed immediately after lighting and the key removed.

§ 24. THE CAPTIVE BALLOON.

Serves for reconnoitring, observing, signalling, and for obtaining continuous scientific records of meteorological data in the atmosphere.

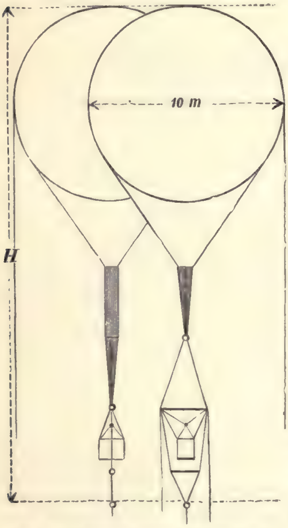

FIG. 34.—Renard's system of suspension.

1. General specifications.—Must be made of strong materials (*cf.* §§ 3, 4, and 5), since it has often to withstand strong gusts of wind (*cf.* § 19, 2, anchor line). Must have tail closed by a safety valve. The tension of the holding rope should be equally distributed over the balloon. The car or instruments must always be hung vertically from the balloon after the system of Cardani. The holding cable should be of hemp, metal, or a combination of the two (*cf.* §§ 6 and 7). The cable must pass over a fixed or transportable windlass, whose guiding roller sets itself according to every change in the direction of the wind.

2. The tail valve.—Must open of its own accord with a small excess pressure (*cf.* § 5).

Object.—To prevent the escape of gas under the influence of the pressure of the wind and the swings of the balloon, as well as to prevent the entrance of air into the balloon, and to diminish diffusion. In case the balloon inadvertently breaks away, it prevents its bursting.

Forms.—(a) *Plate valves* (*cf.* § 14), which open towards the

outside. The valve rope of the upper valve is led either through the plate itself or through the side of the tail directly out of the balloon.

(b) *Membrane valve* (due to Graf v. Zeppelin).—A rubber membrane stretched on the rim of the valve lies against the convex surface of a metal shell fixed in the middle of the rim. The excess pressure allowable is regulated by the strength and tension of the membrane (*cf.* *I. A. M.*, 1900. Special number, 1902. Vol. 1).

3. **The holding rope and the car suspension.**—The holding rope must be fastened at the balloon hoop to the middle point of a rope cross, or star, or to the end of a cone of ropes. It is also possible to fasten it to the ends of a beam fastened over the balloon hoop.

The suspension of the car is accomplished either by fastening it to a point in an elliptical ring (Yon), or to a rod, held perpendicularly to the direction of tension of the cable. The car is prevented from tilting by diagonal ropes.

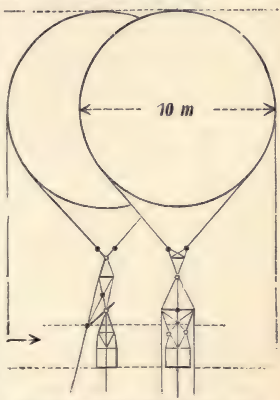

FIG. 35.—Hervé's system of suspension.

Forms.—Renard's system (*cf.* Ledieu, *Le nouveau matériel naval.* Paris, 1890) (fig. 34).

Hervé's system (fig. 35).

Hervé-Meyer's system (*cf.* *Aëronautics*, May 1894).

Yon's system (fig. 36. *Cf.* G. Yon et E. Surcouf, *Aérostats et aérostation militaire à l'exposition universelle de* 1889, Paris, 1893 ; Banet Rivet, *L'Aéronautique*, Paris, 1898, p. 257).

Besançon's system (*cf.* *L'Aé.*, October 1896, p. 236).

4. **The cable.**—Determined by the lift of the balloon (*cf.* Table XVI.), the pressure of the wind against the balloon (*cf.* *I. A. M.*, 1899, p. 76 ; Wagner, *Einfluss des Windes auf das Tau eines Fesselballons*), and against the cable (*cf.* § 19, 2), and by its own weight (*cf.* §§ 6 and 7).

The pressure of the wind against the envelope of the balloon is most conveniently taken as the basis from which the strength of the cable is calculated (*cf.* § 19, 2). Let R be the pressure of the wind, D the diameter of the balloon, v the velocity of the wind, ζ a coefficient depending on the form of the envelope ($=0{\cdot}025$ for a spherical envelope, according to Renard), K the breaking modulus of the material of the cable, s the cross section, and d the diameter of the cable, then—

$$R = \zeta D^2 v^2$$

and

$$s = \frac{R}{K} \text{ in sq. mm.},$$

whence

$$d = \sqrt[2]{\frac{s.}{\pi}}$$

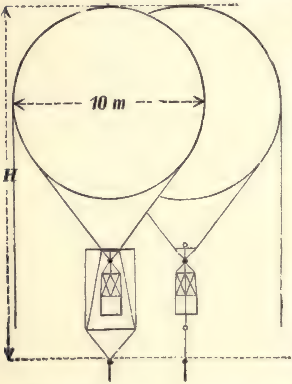

FIG. 36.—Yon's system of suspension.

The cable itself forms the *telephone wire* when a wire cable is used; with a hempen rope the telephone wire must be wrapped around the cable, to allow for expansion or contraction due to changes in the humidity of the air.

5. **The cable clasp.**—Specifications (according to Rudeloff). The ends of all parts of the cable must be fastened with equal security, and the side pressure necessary to produce the requisite frictional resistance must be distributed over a sufficiently long length of the cable. The bending of the cable must be as small as possible, and the telephone connections must not be broken in the clasp.

Forms of cable clasps.

(*a*) The rope is twisted round the axis of the windlass. Fasten by knots, splicings, thimbles with rings, Felton and Guilleaume's friction rope fastener, Becker's fastener, or Scheele's rope clasp.

(*b*) The rope is fixed in the axis.

Conical box with inlaid ring, with a metal mould, Kortüm's rope clasp, Baumann's rope-grip.

According to Martens, Kortüm's rope clasp (fig. 37) has the

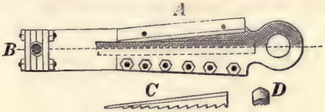

FIG. 37.—Kortüm's rope-clasp.

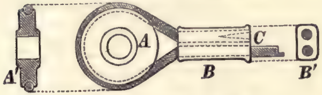

FIG. 38.—Becker's clasp.

greatest strength, then Becker's clasp (fig. 38), and Baumann's rope grip (fig. 39) (*cf.* *Seiler-Zeitung*, 1893–4, 'Researches by Rudeloff'; A. Martens, *Mitteilungen a. d. Kgl. techn. Versuchsanstalt*, Ergänzungsheft V., 1888).

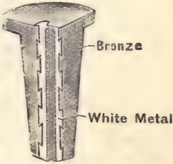

FIG. 39.—Baumann's rope-grip.

The twisting of the cable must be allowed for by laying the holder in a ring with ball bearings. A Cardani holder is to be recommended on account of the frequent lurches and shakings of the balloon.

6. **The maximum elevation of captive balloons.** — The maximum elevation depends on the lift A of the balloon, on the total weight of the load G carried by it, excluding the cable, and on the weight of the unrolled cable. If the weight of the cable is a kg. per metre, a captive balloon ascending vertically would attain a height of—

$$h = 8000 \frac{A - G}{A + 8000a} \text{ metres.} \tag{26}$$

at a temperature of 0° C.

Example.—The lift A = 500 kg., weight of balloon and observer G = 400 kg., 100 m. cable weigh 12 kg.

$$h = 8000 \frac{500 - 400}{500 + 8000 \times 0{\cdot}12} = 548 \text{ metres.}$$

§ 25. THE PARSEVAL-SIGSFELD KITE-BALLOON (Drachenballon).

This form of balloon is manufactured only by A. Riedinger in Augsburg. It combines the peculiarities of the kite with that

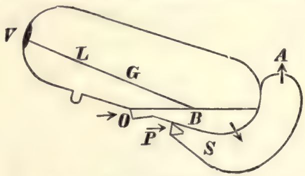

FIG. 40.—Principle of kite-balloon.

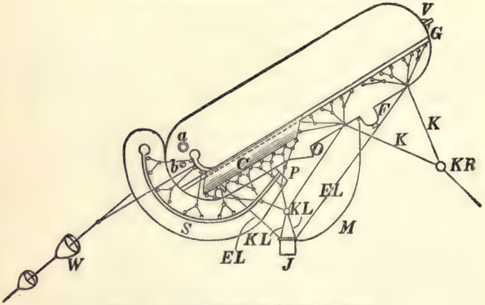

FIG. 41.—Parseval-Sigsfeld's kite-balloon.

F = mouth.	M = valve rope.
P = mouth of the steering bag.	KL = car rope.
O = mouth of ballonet.	J = car.
C = sail.	*a* = hole for emptying balloon.
S = steering bag.	*b* = hole for emptying ballonet.
V = valve.	

of the balloon, without the necessity of a strong stiffening framework, and can be used in a strong wind.

Construction (*cf.* fig. 40).—The part G, for gas, is completely closed, and beneath it is a *ballonet* which fills automatically with air, the opening O facing the wind. The excess air flows

into the rudder bag S, which also fills with air through the opening P, the exit for the air being at A. The opening at A is smaller than that at P. The envelope is without net, which is replaced by a belt round the equator which carries the rope and car. When the cable is run out the balloon rises, the gas in G expands and presses against the upper wall of the *ballonet* B. A valve line L passes from this wall to the valve V, which works, therefore, automatically, and prevents any danger of bursting.

To obtain equipoise, three separate systems are used—a rudder, a sail at the rear of the equator, and wind sails (W.) behind the wind-shadow of the balloon.

A 600 cb. m. kite-balloon at a height of 1000 m. remains steady in a wind of 20 m. per second.

Used by the Balloon Divisions in Germany, Austria, France, Russia, Italy, Spain, Switzerland, United States, Sweden, and Roumania, also as a scientific registering balloon at Reinickendorf-west, near Berlin, and Trappes, near Paris. (*Cf.* v. Parseval, "Der Drachenballon," *Z. für L.*, 1894; also *I. A. M.*, 1897, p. 42; 1898, p. 79; 1899, p. 51; 1901, p. 60).

Attachment and suspension of car. *Cf.* fig. 41.

§ 26. THE FREE BALLOON WITH *BALLONET.*

Meusnier's system enables the form of the balloon to be maintained for lengthy periods, by pumping in air to replace the escaped gas, making it much easier to maintain the balloon at the desired height (*cf. L'Aé.*, 1881; Moedebeck, *Handbuch der Luftschiffahrt*, p. 152; "De Rossi Palloni Postali," Lauciano, 1894; *Revue du Génie*, 1902; "Voyer les découvertes aéronautiques du Général Meusnier," *I. A. M.*, 1905).

§ 27. THE PARACHUTE BALLOON.

A combination of a balloon and parachute, of such a form that the balloon can be torn open. Principally employed for public exhibitions.

Construction.—1. Using the upper hemisphere of the envelope of the balloon as a parachute, a strong cane or metal ring is laid round the edge of the hemisphere, to which all the net meshes and goose's feet of the supporting net are fastened. The lower hemisphere is either torn away or forced up against the upper hemispherical shell on opening the valve (*I. A. M.*, 1901, p. 167; Frl. K. Paulus, *D. R. P.*, 118,834).

2. Instead of being surrounded by a net the balloon is covered by a parachute in the form of a net covering. The envolope of the balloon must be arranged to fall away when torn open.

§ 28. REGISTERING OR SOUNDING BALLOONS.

Serve for scientific purposes, carrying recording instruments (principally barographs, thermographs and hygrographs) to heights unattainable by man, being first suggested for this purpose by Charles Renard (*cf. Revue de L'Aé.*, 1893, p. 1).

Materials.—The best Japan paper is used for the envelope, weighing when varnished 50 gm. per sq. m., and having a tearing stress of 50 kg. per metre breadth. Teisserenc de Bort uses other kinds of strong paper. Any strong light material may, however, be employed, and Assmann has recently introduced india-rubber balloons with parachute network. These gradually increase in size as they ascend, until they burst; they have attained heights of 20 km. and over. The instruments fall under the parachute or under a small balloon (*cf. Ergebnisse der Arbeiten am Aëronautischen Observatorium in den Jahren* 1900 *and* 1901, by R. Assmann and A. Berson, Berlin, 1902).

Rubber balloons.—The Continental Caoutchouc- und Gutta-Percha Company of Hanover have manufactured rubber balloons of the following dimensions for the Kgl. Preussische Aëronautische Observatorium:—

Diameter in mm.,	1000	1200	1400	1600	1800	2000
Contents in cb. m.,	0·52	0·91	1·44	2·15	3·06	4·20
Surface in sq. m.,	3·14	4·52	6·15	8·06	10·18	12·56
Weight in gm.,	420	676	922	1204	1528	1888
Buoyancy of hydrogen-gas in gm.,	575	1000	1585	2365	3370	4620
Buoyancy of balloon in gm.,	155	322	663	1161	1842	2732

Characteristic properties of rubber balloons.—They can rise until expanded to about $2\frac{1}{2}$ times their original diameter, equal to 15·6 times their original volume, and can reach a height corresponding to a pressure of $\frac{760}{15 \cdot 6} = 48$ mm., *i.e.* more than 20 kilometres. Under especially favourable conditions still greater heights have been reached in practice, using tandem recording balloons; *e.g.*, a tandem recording balloon sent up from Strassburg, in August 1905, registered a pressure of 19 mm., or a height of 25,800 m. When filled to their natural capacity the buoyancy, and therefore velocity, increases steadily during the ascent, causing the recording instruments to be well ventilated. They burst at their maximum altitude, and, provided that they are not too badly damaged, may be repaired for further ascents. They require little gas, are easy to handle, and cheap.

Hergesell has drawn up the following laws and table for rubber balloons:—

The diameter of a tight balloon at different heights varies inversely as the cube root of the corresponding pressures.

$$\frac{D}{D_0} = \sqrt[3]{\frac{p_0}{p}}. \tag{27}$$

TABLE FOR THE USE OF RUBBER BALLOONS.

$g : g_0$ = relative amount of ventilation.

Density of air.	Height, metres.	$\frac{D}{D_0}$.	$\frac{v}{v_0}$.	$\frac{g}{g_0}$.
1·25	20	1·00	1·00	1·00
1·19	500	1·02	1·01	0·96
1·13	1,000	1·04	1·02	0·92
1·07	1,500	1·05	1·03	0·88
1·01	2,000	1·07	1·04	0·84
0·96	2,500	1·09	1·04	0·80
0·91	3,000	1·11	1·05	0·77
0·87	3,500	1·13	1·06	0·74
0·82	4,000	1·15	1·07	0·70
0·78	4,500	1·17	1·08	0·67
0·74	5,000	1·19	1·09	0·65
0·70	5,500	1·21	1·10	0·62
0·66	6,000	1·24	1·11	0·58
0·63	6,500	1·26	1·12	0·56
0·59	7,000	1·29	1·13	0·54
0·56	7,500	1·31	1·14	0·51
0·53	8,000	1·33	1·15	0·49
0·50	8,500	1·36	1·16	0·46
0·47	9,000	1·39	1·18	0·44
0·45	9,500	1·41	1·19	0·43
0·42	10,000	1·44	1·20	0·41
0·37	11,000	1·49	1·22	0·36
0·32	12,000	1·57	1·25	0·32
0·27	13,000	1·67	1·29	0·28
0·23	14,000	1·76	1·33	0·25
0·19	15,000	1·87	1·36	0·21
0·18	16,000	1·91	1·38	0·20
0·16	17,000	1·99	1·41	0·18
0·14	18,000	2·07	1·44	0 16
0·12	19,000	2·18	1·48	0·14
0·11	20,000	2·25	1·50	0 13
0·08	22,000	2·27	1·51	0·10
0·06	24,000	2·28	1·51	0·08

The velocity of ascent varies inversely as the sixth root of the corresponding pressures.

$$v = v_0 \sqrt[6]{\frac{p_0}{p}}. \tag{28}$$

The maximum height attainable by an elastic balloon depends solely on the limit of expansibility of its material.

Assmann's new barothermograph, which is suspended from the balloon by means of a light parachute net, weighs from 400 to 550 gm. The cotton net and silk parachute weigh 350 to 400 gm. It is convenient for many purposes, especially for the recovery of the instruments, to send up two balloons tandem-wise, the lower balloon automatically emptying itself at a certain height (*cf.* Assmann and Berson, ***Ergebnisse der Arbeiten am Aëronautischen Observatorium*** 1900 ***and*** 1901. Berlin, 1902. "Protokoll über die 20–25 Mai, 1902, in Berlin Abgehaltene 3 Versammlung der Internationalen Kommission für wissenschaftlicher Luftschiffahrt, *I. A. M.*, 1903, 5"; Hergesell, *Das Aufsteigen von geschlossenen Gummiballons*).

Paper balloons.—Renard has given the following table connecting the size of the balloon with the maximum height attainable for unloaded balloons made of Japan paper. The values are purely theoretical ones (*cf.* § 1, 6).

MAXIMUM HEIGHTS OF SOUNDING BALLOONS OF DIFFERENT SIZES (Renard).

n.	Height, km.	Volume, cb. m.	*n.*	Height, km.	Volume, cb. m.
2	5·5	0·06	30	27·5	221
3	9	0·22	40	29·5	524
4	11	0·52	50	31·3	1,020
5	12·8	1·0	100	37·0	8,780
10	18·5	8·2	200	42·5	65,400
15	21·5	27·6	500	49·5	1,020,000
20	23·9	65·4	1000	55	8,200,000

In this table the coefficient of safety has been taken as 2. According to § 1 the maximum size which can be given to a Japan paper balloon is 440 cb. m., which, unloaded, cannot attain a height of more than 30 km. (On this point consult Renard's work: "Sur l'emploi des ballons perdus pour l'exécu-

tion des observations météorologiques à grandes hauteurs." *R. de l'Aé.*, 1893 ; *Mémoire presenté à l'Académie des sciences le* 5 *déc.* 1892.)

§ 29. PILOT BALLOONS.

Small paper or rubber balloons which serve to determine the direction of the wind in the lower strata of the atmosphere. They are usually furnished with cards of enquiry as to the place of descent, and are used exclusively for scientific investigations on the direction of the wind.

§ 30. MONTGOLFIÈRES OR FIRE BALLOONS.

Montgolfières (or hot-air balloons) must be very large in size, in order to lift, say, a man in addition to their own weight, since the buoyancy of warmed air is very small.

The larger the volume, however, and the greater is the difficulty of heating the contained air uniformly ; besides this, small portions of the envelope continually catch fire in the filling process.

Montgolfières are used at the present time only for purposes of amusement, and may easily become a source of danger from fire in unskilled hands. In America they are still used for exhibition purposes. Their lift may easily be calculated from the following table :—

The weight P of 1 cb. m. air warmed to $t°$ C. at a pressure of b mm. is—

$$(29) \qquad P = \frac{1{\cdot}293}{1 + 0{\cdot}003665\,t} \cdot \frac{b}{760}.$$

TABLE OF THE WEIGHT OF 1 CB. M. AIR.

Temperature °C.	Weight of 1 cb. m. air in kg.	Buoyancy as against 1 cb. m. at 0° in kg.	Temperature °C.	Weight of 1 cb. m. air in kg.	Buoyancy as against 1 cb. m. at 0° in kg.
0	1·293	0	50	1·093	0·200
5	1·270	0·023	60	1·060	0·233
10	1·247	0·046	70	1·029	0·264
15	1·226	0·067	80	1·000	0·293
20	1·204	0·089	90	0·972	0·321
30	1·165	0·128	100	0·946	0·347
40	1·128	0·165			

In practice it is not possible to warm the air in a balloon above 80° C. The behaviour of the fabric, when warmed to the temperature to be attained, must be thoroughly tested before the balloon is built. The diminution of temperature with height increases the buoyancy of the Montgolfière, whilst the cooling of the hot air by radiation and by the expansion of the gas under the diminishing air pressure diminishes it. Those parts of the balloon which may easily come into contact with the fire must be impregnated with suitable solutions.

§ 31. ROZIÈRES.

A combination of the Montgolfière and the gas balloon, in which the danger of damage by fire is enormous. It is named after Pilâtre de Rozière (born at Metz on the 30th March 1757), the first aeronaut to attempt a balloon voyage. He was the first victim of aeronautics, being killed in one of his balloons at Boulogne on 15th June 1785.

In spite of its obvious defects, the idea lying at the base of it —to render possible journeys of long duration by warming or cooling the gas—is worthy of respect.

CHAPTER V.

KITES AND PARACHUTES.

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A.—*KITES.*

§ 1. DEFINITION. HISTORY.

Any body may be designated a kite (German, "Drache"; French, "cerf volant"; Dutch, "vlieger") which is specifically heavier than air, but which can nevertheless be maintained hovering in the air by utilising the unequal distribution of the horizontal wind pressure on one or more inclined planes, while held fast by one or more lines to the ground. By line we mean here, without regard to the material, the wire, cable, rope, or cord by which the kite is connected with the earth.

Kites were first used for scientific purposes one hundred and fifty years ago (A. Wilson, 1749; Franklin, 1752). After this it was not until 1894, with the exception of a few isolated experiments, of which the most worthy of note are those of D. Archibald, 1883, that the use of kites for meteorological purposes was first taken up scientifically in the United States. The first recording apparatus with clockwork raised by kites was sent up from Blue Hill on 4th August 1894. Professor Marvin made his important studies on kites in Washington in 1895, and arranged the seventeen kite stations of the United States Weather Bureau during the summer of 1898.

The raising of men by means of kites was also achieved by Major Baden-Powell in England, by Lieutenant Wise in America, and by the military balloon corps in Russia in the same year, so that in the autumn of 1898, at the Russian Naturalist Meeting, various persons were lifted to low heights. Since the whole subject is as yet in its infancy, it is natural that its methods and expedients are still in process of development; in the

next few years noteworthy inventions in this field may therefore be looked for.

The unexpected development of meteorological kite-technics in the last few years may be attributed principally to three causes—the discovery of stable kites of great lifting power, the construction of extremely light meteorological recording apparatus, and the use of steel wire as the line. By these means it has been possible to obtain good records by means of kites at altitudes of from 4 to 5000 metres.

Arrangements for carrying out meteorological kite ascents on a large scale are in progress at the Observatories at Blue Hill, near Boston; at Trappes, near Paris; and at Lindenberg near Beeskow; and on a lesser scale at Hamburg, Pavlofsk, Wilna, Kutschino, and some other stations. They are not at present in use at the stations under the Washington Weather Bureau.

§ 2. OBJECT OF KITES.

The objects of a kite, which is not to serve merely for purposes of amusement, may be threefold:

(*A.*) To exert a pull in a horizontal direction by means of which a raft or boat, say, may be moved, or

(*B.*) To raise oneself or some object to a certain height; or

(*C.*) To study the peculiarities of certain flying bodies by its behaviour.

(*A.*) Even in the first connection there is much to be attained. Since wrecks are constantly occurring in winds blowing towards the land, kites can often be employed to make connection with the land, and thus lives may be saved.

For this purpose a proper control of the kite is important; this may be effected either by a suitable rudder attached to the kite, or by two strings fastened to the right and left of the kite similar to horse-reins, the latter being the safer method. In this way one can deviate the direction at least 15° from that of the wind, towards the side on which the land lies. Finally the kite is allowed to fall by loosening one string. It would be very desirable for all ships to be provided with kites for use in such cases, or to have on the staff at least one man having a knowledge of kites and able to make one up quickly; naturally it need not be able to soar very high.

(*B.*) Much more frequently kites are wanted for lifting purposes, when the horizontal motion of the kite is only an unavoidable evil. In this case either only the kite itself is to be lifted, as when we wish to determine the height of the clouds, or to use it as an agreed signal; or, as is more

frequently the case, the problem is to lift a load by means of the kite—either a small load, such as a meteorograph weighing 1 or 1¼ kg. to a great height, or a heavy load (a man) to a lower height.

For a kite intended for these purposes the principal requirements are: (*a*) lifting power, (*b*) stability. The lifting power must be sufficient to enable the kite to soar in a feeble wind, and such that, when it has wind enough, it soars steeply,—that is, making the greatest possible angle with the horizon. Its strength should be proportional to its size.

The stability is shown by the kite flying quietly with no bending or "shooting," *i.e.* flying rapidly downwards with the head forwards and a strong pull to the side; nor "diving," *i.e.* flying forwards and downwards with head downwards and free

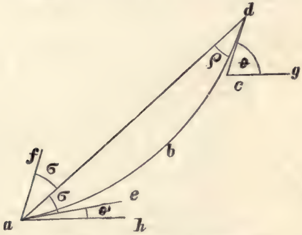

FIG. 42.—Curvature of kite-line.

string. Unfortunately the conditions for (*a*) and (*b*) are in part opposed to one another, since very lightly-built kites show (*a*) well, but not (*b*), on account of the inclination due to unequal warping under strong wind pressure, and since, to procure great stability rudder-surfaces or tails are necessary, which increase the weight of the kite. Stiffness, especially of the front edge, increases both (*a*) and (*b*), and is very necessary in a good kite. Kites intended to raise scientific apparatus aloft must have the line inclined to the horizon at an angle of 50–70° at its upper end, and must be able to soar safely with a wind velocity (measured at a height of 15 to 25 metres above the ground) of 4½, 5, or at most 6 metres per sec.; and in a wind of 10 metres per sec. on the anemometer (which corresponds ordinarily to 15 to 20 metres per sec. above 500 metres) must still be stable in flight.

The string, on account of its weight and of the pressure of

the wind on it, possesses a curvature convex downwards and to leewards, the angle which it makes with the horizon decreasing with increasing distance from the kite. If only gravity acted, the string, if homogeneous, would assume the form of a catenary, a curve more curved in the lower part than in the upper. The curvature is not only increased by the addition of the pressure of the wind on the string, but the difference in the curvature above and below is decreased, perhaps even reversed.

Let ah or cg be horizontal lines (see fig. 42), the curve abd that of the string, and ae, cd the tangents to it; then in practice $\angle\rho = \angle\sigma$ (very nearly), and af is parallel to cd; consequently a simple relation is deducible between the angle dcg or θ, the angle of elevation of the kite $dah = \phi$, and $eah = \theta' = \phi - \sigma$; θ remains practically constant during the ascent, while θ' gradually diminishes as the line is run out. If the line is horizontal, then if $\theta = 60°$, $\phi =$ about $30°$, and to pay out more wire does not further increase the height.

It is, then, this bending of the string which sets a limit to the height of kite ascents. The kite in ascending describes the same curve, only reversed, in the air (the wind remaining constant), so if abd (fig. 43) is the shape of the string, then aed is the path of the kite, and the less the initial direction of the string is inclined to the horizon, the lower will be the height attainable by the kite. The work of hauling in the line per unit length increases with the altitude of the kite, on account of the greater wind velocity aloft; furthermore, it is unprofitable to let out more line as soon as the initial angle becomes less than 10° to 20°, and quite purposeless when it is 0°, as no further increase of altitude would result.

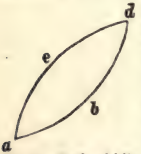

FIG. 43.—Path of kite and shape taken up by string.

A greater altitude may be attained by attaching other kites to the string by means of short branch strings (20 to 40 metres), which have also to be raised by the main string.

(*C.*) The application of kites to testing flying models has hitherto only been attempted by Hargrave, who for this purpose drew a wire h metres above the ground between two masts $2\,h$ metres apart, and from the middle point allowed a string to hang, on which he fastened the model. This he allowed to rise like a kite, so that if the stability were imperfect, it could strike nothing. Large models or machines may be carried by specially designed kites. With some practice it is possible to tell how much of the motion is due to the kite above and how much to the models. The method is worthy of wider application than it has hitherto received.

§ 3. THE STRING.

Material.—For long lengths steel wire is the only material which is employed at the present time; for shorter lengths hemp or China-grass. The relation between the tearing stress and the weight of unit length is, indeed, about the same for silk as for steel wire, but the much greater diameter of the former would cause a greater wind-pressure on the string, and consequently prevent the attainment of great heights when using silk strings, leaving totally out of consideration the much higher price of the latter.

APPROXIMATE DIAMETERS AND WEIGHTS OF STRINGS OF GIVEN BREAKING STRESSES.

Breaking stress in kg.,		50	75	100	125	150	175	200
Diameter in mm.	Steel wire,	0·48	0·57	0·67	0·76	0·86	0·96	1·06
	Hempen cord,	2·4	3·0	3·3	3·6	3·9	(4·3)	(4·6)
Weight in kg. per km.	Steel wire,	1·2	1·9	2·7	3·6	4 6	5·7	6·9
	Hempen cord,	5	7	9	12	14	(16)	(18)

These numbers apply to the untinned wire. Tinned wire, especially of the smaller sizes, has a somewhat lower breaking stress—25 per cent. lower for wire of 0·7 mm. diameter, 8 per cent. lower for wire of 1 mm. diameter. The numbers are average values; in long lines we must always allow for somewhat weaker places, and, generally speaking, the wire should not be loaded to more than half its breaking stress as given above, while particular care should be taken to injure no part in handling it. In steel wire rust and kinks especially must be prevented. Untinned wire must therefore be constantly kept oiled, especially after being wet, by being drawn through two dusters or rags, the first being to dry the wire and the second to oil it. Temperature changes also cause a deposit of rime on the wire, which easily produces rust, and must be removed. Tinned wire is far more pleasant to work with in these respects, although it, too, should be kept dry and slightly greased. Kinks are caused in hard steel wire by drawing together the loops, which are formed as soon as the tension of the wire is relieved. It is absolutely necessary that they should be prevented or cut away. Every sharp bend in the wire also carries danger with it. In connection with ropes, in addition to the ordinary deterioration through friction, one special source of trouble arises in kite strings, *i.e.* the string when slightly damp is liable to give off sparks due to atmospheric electricity; these cause defects and a large decrease in the breaking stress of the rope.

The string must not be made of conducting material with small non-conducting lengths, but all should be made conducting.

Tension.—Since in addition to the two tensions acting at the ends of the string, there are two other forces acting on the whole length, the tension is not the same at every point. On account of gravity the tension diminishes downwards by the weight of the vertical projection of the corresponding piece of string. If, in fig. 44, t is the tension at the upper and t' at the lower end of the string, then $t' = t - hw$, where w is the weight of unit length of the string or wire. On account of the pressure of the wind the tension is also altered, but the alteration has not yet been investigated.

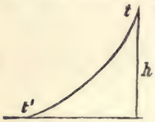

FIG. 44.—Tension in string.

§ 4. JOINTS.

The joints between the separate parts of the string are usually its weakest points, since the breaking stresses of the threads and wires diminish under the pressing and twisting necessary to make a good joint. Since the strength of the line is that of its weakest part, the greatest care must be exercised in making the joint. This will be rendered easier if the following precautions are taken :—

(*a*) In order that the joint may not become loose by slipping, the parts of the joint must grip one another, so that the stronger the pull on them the firmer they become. With soft material (string) we must bind the joint with steel wire. The joint between two wires may be made by pressing the wires together between plates by means of screws, but it is usually better to twist together in parts (binding, knots, splicing).

(*b*) Since the breaking stress decreases with a decrease in the radius of the curvature, the best joints are those in which the wire and string are but little bent in the middle portion of the splicing, being bent more sharply only some distance away, giving a portion in which the tension is taken up by friction.

Joints between rope and rope.—The better knots fulfil the above conditions. The bow knot possesses good properties, especially great tearing stress and absolute firmness; it is readily undone even after great tensions have been applied to it, since it never draws itself together, the pressures in it being released as soon as the forces are released. Other good

knots for special purposes are reef-knots (cross knots), fishermen's tack; the ordinary parcel knot used by booksellers and others is also a rationally strong knot. Still stronger, being less liable to give than the rope itself, is splicing, in which the separate threads are plaited through one another.

The joint between wire and wire is also termed splicing, although it is not formed by plaiting, but merely by twisting the two wires together; these hold together owing to friction and resistance to change of shape. The shorter the twistings the greater the friction, but the weakening of the wire is also greater. Short hammered splicings break under tension at one of the ends where the wire emerges, never in the middle. Sharp bending is free from risk only when at least 20–50 per cent. of the tension is taken up by friction. Best splicing:

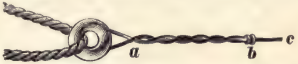

FIG. 45.—Bull's-eye attachment of rope and wire.

In the middle about 4 cm. with short even turns at ½ to 1 cm. apart, right and left of this 20–40 cm. with long turns, one winding = 4 cm., then the short ends stretched out in a straight line and finally bent at right angles and made fast by two short turns. It is unnecessary and dangerous to solder this splicing. If only long windings are to be used the splicing must be about a metre longer.

A joint between wire and rope is best effected by means of a thimble through which the rope is passed. With ordinary bull's eyes (fig. 45) both a and b are weak places, and if the angle at a is $>120°$, the tension on each branch is $> t$ where t is the tension in c. Hence the wire is easily broken at a, when

FIG. 46.—Köppen's clutch thimble.

the splicing is carried too far. At the Blue Hill station this part of the wire is consequently taken double, and the splicing long, being made as described above. Köppen's clutch thimble is more convenient and better: the wire enters with a bend of 70 mm. radius, and by bending gradually fastens itself, the firmer the stronger the pull is, and comes out at o, where it is wrapped round the ring, and hooked fast near o simply by bending. The drawing through and fastening is accomplished

in from one to two minutes; since the last 10 to 50 metres of wire are usually spoilt they can be cut away without loss of time and the ring recovered. The ring may be opened by unscrewing; the outer parts are of magnalium, the inner—shown shaded in fig. 46—of brass. It weighs 19 gm.

§ 5. THE BRIDLE.

In order to obtain equilibrium the point at which the resultant of the pressure of the wind acts must be in the projection of the line of the string. Since this point is difficult to determine, and changes with the strength of the wind, this position must be automatically attained by small alterations in the inclination of the kite. In box-kites, where the centre of pressure lies in the interior, it is sufficient to fasten the string at one point on the under side of the kite surface, but with single surfaced and Malay kites a division of the string is unavoidable for stability. This may also fulfil, however, with other types of kites, a further object — the multiple support of the framework against the pressure of the wind. Branching the string to the right and left serves this purpose, while branching it forwards and behind increases the stability.

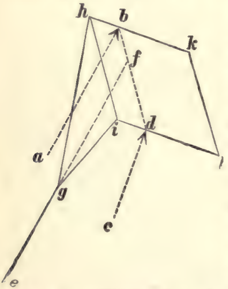

FIG. 47.—Determination of the branching point.

The point at which the single string is branched—the branching point—is found thus:—Let $h\,k$ and $i\,l$ be the profiles of two surfaces of a step kite (see fig. 47), then we may assume that the wind pressure on these is very nearly represented by the two forces $a\,b$ and $c\,d$. Their directions are, according to measurements by Marvin on Hargrave kites, in good kites inclined at only about 10° to the perpendicular to the carrying surface. Researches carried out under water with such models show that $a\,b$ is greater than $c\,d$; the position of f is given by the relation $bf : fd = c\,d : a\,b$. The uppermost part of the string must fall in the line ef, the branching point on the same is chosen from practical considerations—*e.g.* at g; then $g\,h$ and $g\,i$ are the two principal branches of the bridle, from which, if required, secondary branches may

go to other points of the kite which it may be desired to support. It is shown in practice that, as a matter of fact, the pressure line *ef* cuts the front line *hi* of the kite about in the middle.

With similar approximations the centre of pressure of other new forms of kites may be found and afterwards tested.

If the branch *gi* of the bridle is made elastic, then the kite takes up a smaller angle of incidence to the wind with increasing wind. By suitably choosing the elastic cord we obtain a valuable guarantee against the wind pressure increasing too rapidly on the kite, and so decrease the risk of tearing the wire and breaking the kite, enabling smaller wire to be used and a greater height to be attained. The same object may be achieved, though not so perfectly, by introducing a weaker piece in *gi*; this tears before the principal wire is in danger.

§ 6. THE WINCH.

A windlass or winch is necessary for drawing in the string even when rope is used, as soon as we deal with large kites and long lengths, and is unavoidable when we are using wire as the string, since this cannot be held fast by hand. Large kite winches, driven by motors, have been installed at Blue Hill (Boston), Washington, Trappes (Paris), and Lindenberg (Beeskow). For hand driving a convenient form of winch is made by Marvin in Washington; this form is in use in Hamburg (Seewarte). It is mounted on a turn-table, has counting mechanism and tension measurers on the crank; the wire leads from the drum directly to the kite.

In order to protect the staff and machine from wind and rain, a hut capable of being rotated is very useful, the wire being led through a large door. In addition to this a large hut or shed is necessary for preparing and building the kites.

§ 7. FORMS OF KITES.

Innumerable forms are possible, but only a few can be employed practically.

A. **Plate-kites.**—Have in general too little stability and too small an angle of ascent.

The six-cornered kites, with which Baden-Powell in England, and others in Russia, have experimented, using four or five arranged tandem-wise, to investigate the raising of scouts, can be folded. The English kites are 12 sq. m. in area and have one long stick (backbone) and two cross bars. They fly without

tails. In order to ensure stability two strings fastened at a considerable distance apart are employed. Four English military kites coupled behind one another are depicted in fig. 58.

B. **Malay kites.**—Transverse curved lasts, as used in different parts of Asia, give these kites great stability. W. A. Eddy constructed a very practical kite of great stability in America in 1893, using two sticks of equal length; the horizontal cross piece is placed 18 per cent. of the length from the top of the vertical side. The ends of the cross-pieces are bent backwards in a bow and connected by a cord.

For kites of 2 sq. m. surface and upwards Köppen has applied the following construction:—A piece of white metal is cut out by a tinsmith in the shape shown in fig. 48; in the middle it is strengthened with a cross sheet soldered on, and is folded along

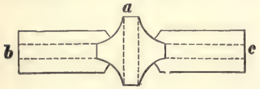

FIG. 48.

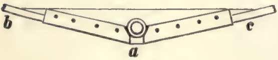

FIG. 49.

FIG. 50.—Malay kite.

the dotted lines shown, which have to enclose the backbone *a a* and the cross-pieces *b* and *c*. This is nailed on to a thin triangular board (see fig. 49), and the cross-pieces *b* and *c* inserted as shown. The calico (or other material) is attached to this framework by means of suitable hooks, and when the kite is to be stored away can be detached from *b* and *c* and wrapped round the backbone.

These kites, known under the name of Malay kites, fly high and well, without tail, even in a feeble wind ($4\frac{1}{2}$ to 8 m. per sec.) (see fig. 50).

C. **Hargrave or box-kites** have displaced all other forms of kite, although much more complicated, more breakable, and heavier to build and to transport. They are, however, when carefully constructed, the most stable kites known at the present time, as they ascend steeply and exert the greatest force. They are therefore especially to be recommended for raising a weight to great heights into the air. The kite consists of two or

more cells of different cross sections; figs. 51, 51*a*, 51*b* show a few examples of this type of kite; a vertical section shows at least two lifting surfaces in any plane, and two at right angles to this plane (*cf.* fig. 52—the four black lines), of which

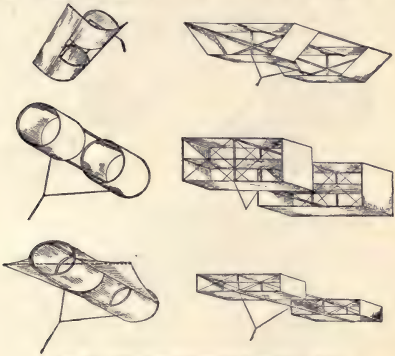

FIG. 51.—Different patterns of Hargrave kite.

the latter are connected by vertical fabric surfaces (shaded in fig. 52).

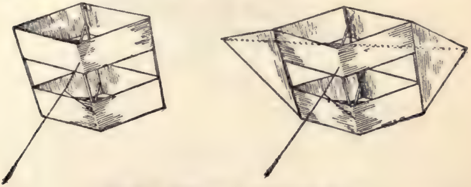

FIG. 51*a*.—Patterns introduced by Potter.

The build of a Hargrave or box-kite may be of very different patterns. Hargrave himself usually arranges to have two longitudinal rods, which alone serve to bind the cells together, while the remaining longitudinal rods have only the length of a cell;

these form the corners of the kite, and in Hargrave's latest models are only held in position by diagonal ties which stretch from them to the longer longitudinal rods. On the other hand the meteorological high-flying kites used in America are all built on a different plan, and almost exclusively as right-angled prisms in which all the edges, and also all the edges of the cells, stretched with fabric, are formed of wooden strips. A good

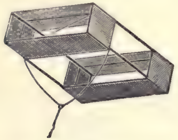

FIG. 51*b*.—Hargrave kite.

FIG. 52.

model of this type is Marvin's kite (fig. 53), which has been employed at the kite stations under the Washington Weather Bureau, and also for the majority of ascents at the Hamburg Seewarte. The front cell has three, the rear two, lifting surfaces. The build is somewhat clumsy, but repairs are simple to execute, since single broken ties are easily removed and re-

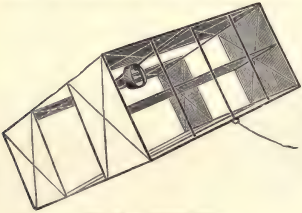

FIG. 53.—Marvin kite.

placed by new ones ; diagonal stays are all made to fit, and can be quickly reinserted in their proper places when it is necessary to loosen them. The string is fastened to the middle point of the lower edge of the front cell of the kite, and has one branch to the rear edge of the front cell and a second branch to the rear cell. If the first branch is elastic or arranged to break

first, then with an increase in the pressure of the wind the pull is exerted on the second branch and the kite lies somewhat flatter. In the Hargrave kite without "between sail" the first branch of the bridle must usually be fastened to the rear edge of the front cell.

In the American form of this model the actual building is best carried out by first making the four upright surfaces perpendicular to the main frame and then placing in position the longitudinal rods and horizontal surfaces.

Well-built Hargrave kites weigh 0·6 to 0·8 kg. per sq. m. of lifting surface, and require (at a height of 25 m.) a wind velocity of about 6 m. per sec. to soar.

If the lifting surface of the Hargrave kite, namely that of its front cell, is slightly arched (depth of segment : arc = 1 : 12) it will rise more steeply, at from 60° to 67°, instead of from 55° to

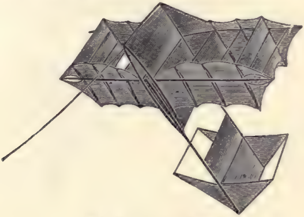

FIG 54.—Lamson kite.

60°. It has proved best to have an arch whose highest point lies far forwards, and whose steep front portion is formed of stiff material,—veneer wood or thin steel plate.

D. **Other types of kites.**—Closely related to the Hargrave kite there are a series of other newer forms of kites, which also consist of several lifting and rudder surfaces, but arranged differently. It is, in fact, very improbable that the best arrangement has as yet been discovered. On the contrary, every one of the known forms has certain drawbacks which it is hoped may ultimately be avoided. Unfortunately it is impossible to predict beforehand what the action of any particular arrangement will be; it can only be tested by patient experiment.

The Lamson kite (fig. 54) (invented in 1897, Portland, Me.) is a form characterised by rising steeply and having great stability; it formed the point of the team of kites in the first

high ascents from Blue Hill. In principle it is a Hargrave kite with large fore and smaller rear cells and curved lifting surfaces. Unfortunately it is difficult and expensive to build, is very fragile, and needs a strong wind.

The Nikel kite (fig. 55) (invented 1898, Vienna) is based on the Kress flying machine, but has at least four pairs of wings; the wings have only stiff ribs on the front side, the back is flexible and is lifted by the wind so that it assumes the appear-

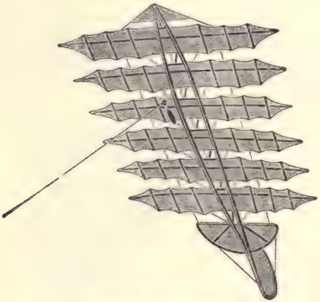

FIG. 55.—Nikel kite.

ance of Venetian blinds. In addition the ends of the wings can bend back, while their middle portions have great stiffness. It is several metres long and is difficult to build.

The Slat kite (invented 1901, Hamburg) has a stiff frame like a Hargrave kite, but its surfaces are arranged like slats of Venetian blinds; its profile is shown in fig. 56, and an oblique view of two forms of it in figs. 57*a* and *b*. The sides of the kite form vertical guiding surfaces. The kite may be built with two or more lifting surfaces. Kites of this form have already made a number of successful ascents at considerable heights, but they are not so stable in a strong wind as the Hargrave kite. Their advantage over the latter lies in the fact that they require only 75 per cent. of the wind velocity necessary for the Hargrave kite, viz., 4·5 m. per sec. as against 6 m. per sec. (at a height of 25 m., about ⅔ of this on the ground), while

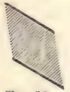

FIG. 56.—Profile of slat kite.

they are at the same time simpler (in the form 57*b*) and less fragile than the Hargrave kite.

The Kutznetzki kite (designed in St. Petersburg in 1903) is a Hargrave kite, the cross section of which is a segment of a circle, so that it has the appearance of two semi-cylinders arranged behind one another, the curved surfaces being against the wind. It possesses excellent stability.

The Lamson and Nikel kites are the only ones of these kites which have been built up to the present on a large scale; the latter only flies when it is at least 6 metres long and 3 metres broad. The slat kite has been tested and satisfactorily flown when of very different dimensions, varying in breadth from 0·3 to 2·0 metres. The Lamson and the slat kites may be folded up for transport, but this is generally impossible with the Nikel kite. The slat kite is most conveniently built with three rigid vertical segments and removable cross ties. Experiments are at present being carried out with a view to perfecting the Nikel and the slat kites. The main problem is to discover a kite which will soar easily, while possessing the strength and simplicity of the Malay kite combined with the stability of the Hargrave kite, and have an angle of ascent not less than the best of these types.

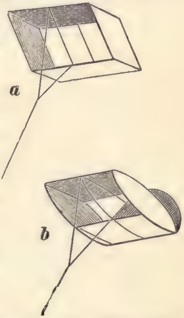

FIG. 57 *a* and *b*.—The slat kite.

Those forms of kites which are bounded by stiff edges may be furnished with advantage with flapping wings, which serve as lifting surfaces in a feeble wind and as steadying surfaces in a strong wind, while increasing the total weight but slightly.

§ 8. TEAMS OF KITES.

A carrying surface of from 5–8 sq. m. is the greatest a kite can possess without becoming clumsy to handle. If more is required, extra kites are fastened to the same string. Such a team of kites has, however, other advantages, viz., regular pull, adaptability to the momentary existing conditions, possibility of attaining great heights. The kites may be coupled either (1) tandemwise, or (2) side by side. In the first system, adopted by Hargrave and Baden-Powell, the uppermost kite is

fastened to the back of the lower one with one or two strings from 10 to 100 ms. long. A team of kites arranged by Baden-Powell is shown in fig. 58, one by Hargrave in fig. 59. The positions of fastening the upper and lower strings to the kites must lie opposite to one another. The second system, due to Eddy, is in use exclusively at meteorological stations; every kite flies on its own branch line (fig. 60), which is attached to the main wire by means of a clamp or otherwise; it is used when a great pull is desired. According to experiments carried out at Hamburg the first system is also excellently adapted to meteorological purposes, the instruments being carried in the interior of the lowest and largest kite of the team. The ascent and landing are rendered much less troublesome since the pull exerted by the kites

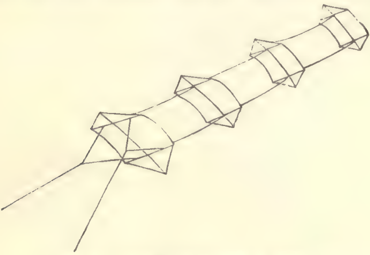

FIG. 58.—Baden-Powell's team of kites.

above breaks the fall. In feeble winds a Malay kite may be employed for the uppermost one of the team. If after 1500 to 2000 metres of wire have been payed out the angle sinks to below 15° or 20° and a greater height is desired, a new kite may be attached by the second method, and so on. If this kite is large —3 sq. m. or more—it is advisable to use a thicker main wire from the junction, otherwise the pull may be too great for the wire (or else the wire above was unnecessarily heavy). We can gradually go over in steps from wire 0·7 to 0·8 mm. diameter to wire of 0·9 to 1·1 mm. as required.

Various systems have been employed for fastening together the main and branch wires. If the size of the main wire is also to be changed at the joint, common or two-ended thimbles may be used for the wires; these give a perfectly flexible joint which can be rapidly made and loosened.

For fastening a branch wire to a uniform wire while paying

out the latter, the best clamp is the form employed in the Aeronautical Observatory in Berlin-Tegel; this only grips on a bend in the stretched wire and is quickly fastened on and removed. The forms of clamps used at Blue Hill and Trappes have been subjected to thorough tests, but are nevertheless more clumsy and dangerous.

The object to be carried by the kite should, whenever possible, be carried inside the kite, and not swing on to the wire. It is then well secured, even if the kite should fall or fly away. Twice the meteorograph in Hamburg (arranged

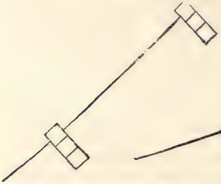

FIG. 59.—Hargrave's team of kites.

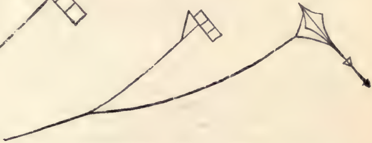

FIG. 60.—Eddy's team of kites.

according to Marvin's suggestion), fastened as shown in fig. 53, flew away 5 to 8 km. in the kite, without meeting with the slightest damage. For lifting men also, this system is much less dangerous than that of suspending a car underneath the kites. The load should be arranged a little in front of, rather than behind, the centre of gravity of the kite, in order not to disturb the balance.

§ 9. THE ASCENT AND LANDING.

In order to raise a large kite it must be brought out some 50 to 70 m. in the direction of the wind, if this be strong, or 100–150 m. if feeble, and then held aloft with stretched line. If the wind tends to force the kite to one side it must be followed; the hold must not be relaxed until it rises squarely, as otherwise damage may easily result.

In landing the fragile types, such as the Hargrave kites, they should be caught whenever possible. If three persons are employed, one may operate the winch, a second catch the kite, and the third attend to the landing roller—a light roller, not too small (radius >7 cm.), which is placed on the wire and allowed to roll on the wire towards the kite; the kite must be

kept under observation, and if unsteady the line should be payed out again and drawn in only when the kite flies steadily and almost vertically overhead. A landing-line 20–30 m. long should be used in strong winds; it should be gripped by the assistant near the kite and drawn rapidly to leewards. If the kite is carried by other kites above it, these landing difficulties, by which the tedious work of several days may be destroyed in a few seconds, are obviated.

§ 10. THE EXPENSES.

The expenses of maintaining kites vary according to the object in view and other circumstances.

The following data may be of use in forming an estimate of the costs:—

(*a*) *Costs of material.*—For a Hargrave-Marvin kite of 6 sq. m. lifting surface the cost, exclusive of the original cost of the production of the shapes and moulds for the metal work, is about 28s. for material, and thirteen days' labour. These kites are easily repaired, since the separate parts can be readily replaced. The simple box-kites, such as those built in Trappes, are much more quickly made, but the repairs of damage are difficult, and often not worth the cost of carrying out.

The wire costs 5s. a kg. Wire 0·7 mm. in diameter weighs approximately 3 kg. per kilometre, 0·8 mm. 4 kg., and 0·9 mm. 5 kg. per km. 1–3000 m. of wire may be bought in one piece, according to the thickness.

A hand winch must be procured, price according to requirements, £5 to £30, if it is to take several thousand metres of wire; if a winch taking only a few hundred metres is sufficient it would cost much less. If it is only desired to experiment in summer, in the neighbourhood of a building, a transportable winch is all that is necessary, otherwise one should be fixed up in a booth which can be rotated—price about £15. A shed for building and making ready the kites must also be provided.

For continuous meteorological work the minimum requirement is the provision of a workshop capable of being heated, and close at hand.

The price of a kite meteorograph is about £30, with, or £20, without, anemometer, exclusive of cost of transport, etc. At least one reserve instrument is necessary if it is desired to be protected against long and continuous interruptions. In regular practice the meteorological conditions at the earth's surface should also be recorded, otherwise full value cannot be obtained from the records at the higher altitudes.

(*b*) The personal expenses are the most important, but depend principally on external circumstances in connection with the kite station. It may be remarked here that two or three persons thoroughly understanding the business should be in attendance for four to six hours during each kite ascent; of these one must take the command and responsibility. In the pauses which occur between the ascents, owing to the wind being too feeble from time to time, the assistants will be engaged in building and repairing kites and other necessary work. It is advisable to have only the first pattern of a kite made outside the station, or much time may be lost in case of a mishap; in the long run it is better not only to have repairs carried out at the station, but to have the kites themselves built there.

B.—*PARACHUTES.*

§ 1. PARACHUTES ALREADY TESTED.

The parachute is a development of the umbrella or sunshade. Experiments with parachutes were made as long as four hundred years ago by Siamese jugglers.

In Europe, the parachute was first described by Leonardo da Vinci, 1514 (G. Tissandier, *La Navigation Aérienne*, Paris, 1886), and Fausto Veranzio, an architect of Venice, 1617. The first successful experiments in Europe, from small heights, were made by Lenormand, 1783 (*Annales des Arts et Manufactures*, par R. O'Reilly, vol. xvi., Paris, 1804); and, from balloons, by Garnerin, 1797 ("Astra Castra," *Experiments and Adventures in the Atmosphere*, by Hatton Turnor, London, 1865, p. 110); the former used at first two umbrellas, strengthened by binding the fish-bone ribs with strings to the handle, to prevent overturning; the latter used a large, specially built umbrella, which he soon, acting on Lalande's advice, furnished with a central opening (together with a tube 1 metre long), in order to diminish the great vibration. J. Garnerin's parachute of 1802 was made of white canvas, and had a diameter of 7 metres; at the top was a ring of wood 25 cm. in diameter, fastened to the canvas by thirty-six short pieces of tape. A wooden hoop, 2·4 metres broad, placed 1·4 metres beneath this, held the fabric half open during the ascent and fall. The vibrations were so great that the car and parachute were often at the same height.

The times of fall, as sometimes stated, seem astoundingly long. Robertson, jun., fell 3000 metres in 35 mins.; Sivel, 1700 metres in 23 mins.—giving velocities of 1·43 and 1·23 metres per sec.; Frau Poitevin is said to have required 43 mins. for a fall of

1800 metres, so that she found her husband packing up the balloon in which she had ascended with him.

The above times of fall were apparently increased by air currents. Calculations by Dr Bräuler (*Centralblatt der Bauverwaltung*, 1889), based on Didion's experiments with small parachutes, give the following final velocities for the fall from great heights, depending on the relation of the weight (including passenger) to the cross section of the umbrella :—

kg. per. sq. m., . .	1	2	4	8	16
m. per sec., . .	2·4	3·5	5·0	6·9	10·0

These values are probably too small on the average even for still air, since the smaller density of the air at great heights is not taken into account.

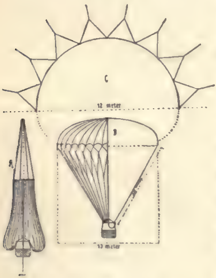

FIG. 61.—Parachute.

Poitevin's parachute, in use thirty-eight times, was stretched with silk ; it was 12 metres in diameter, with a central opening at the top 15 cm. in diameter (it ought to have been larger), and weighed 30 kg.

Ledieu gives the following particulars with regard to the usual French parachute used at the present day (*Le nouveau matériel naval*, Paris, 1890, p. 275. Parachutes).

A parachute required to carry its own weight and that of a man should be able to carry 100 kg. in all, and must be 12 metres in diameter when flat and 10 metres in diameter when arched, and have an area of about 80 sq. m. (*cf.* fig. 61). When folded, the car hangs as shown in fig. 61A, being suspended from the central upper ring of the parachute, and from the air balloon. The ropes between the car and the circumference of the parachute are then slackened, and as soon as the balloon begins to fall the parachute expands and these ropes stretch. The parachute is now detached from the balloon, and the painful drop experienced before the parachute opens itself out is prevented.

If the parachute is cut loose before the balloon has acquired a large downward velocity, it opens (according to Yon) after a fall of at most 5 metres ; the balloon then rises with great velocity owing to its having been relieved of a load of some 100 kg. weight.

In the *I. A. M.*, 1900, p. 76, Frl. Käthe Paulus describes a double parachute, and the precautions necessary in its use. It has no application except at shows, to display a double leap into space before the public.

§ 2. PARACHUTE DESIGN.

For a plane surface, whose centre of gravity lies in itself, and in the middle third of its length, a vertical position is an unstable one for a free fall, and it can only remain in a vertical position momentarily; every chance deviation from the vertical leads to the tilting upwards of the front (or, in the fall, lower) edge, until the surface assumes an inclined or horizontal position (*cf.* fig. 62, where m is the centre of gravity and n the point at which the resultant of the air resistance acts).

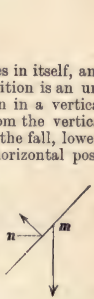

FIG. 62.—Forces on an inclined plane surface.

As one can easily verify by means of a piece of writing paper, ½ to 7 cm. broad, and about three times as long, the fall may take place in one of three different ways:—

(1) If m lies in the middle, and the original position of the sheet is horizontal, the sheet maintains its horizontal position during the fall, with increasing vibrations.

(2) When m lies in the middle and the sheet is slightly inclined at starting, rotation occurs about the longer horizontal axis.

(3) If m is so far to one side that it almost coincides with n, the plate glides downwards with the heavier side in front.

Of these three methods of fall, which are distinguished as hovering, rotary fall, and gliding fall, the first is least retarded and least stable. A piece of paper falls more rapidly and makes more irregular movements when it is let go in a horizontal position than when it is allowed to fall in a strongly inclined position. The second method of fall gives a slow, and the third a more rapid horizontal component, the vertical component being in each case about the same, and much less than in (1). The first method of fall is therefore the most disadvantageous.

Now the parachute differs in two respects from the plate we have been considering; it is not plane, but concave downwards, and it forms with the car and its contents a system whose centre of gravity lies very low. The downward concave form

increases the resistance of the air, but is in the highest degree unsatisfactory for stability; if one allows an arched piece of paper—say a flattish cone or a piece of a cylindrical mantel—to fall with the concave side facing downwards, it turns right over. The parachute is prevented from doing this by the deep position of its centre of gravity, but it tilts sharply to the side, causing great vibration.

The fall will be steadier if an opening is made in the centre; an arched surface oscillates and tends to turn so that the convex side is below, but it falls straighter and not more rapidly than without the hole.

The faults of a parachute may be illustrated by some characteristic mishaps. Ledet met his death owing to his parachute failing to open; Cocking, who used a conical-shaped parachute, met his death on 27th July 1837, because, owing to a break in some part of the apparatus, the car turned over several times in the air, and he was thrown out; Stella Robin lost her life because she remained hanging without protection under the shade, while the parachute bumped violently several times owing to the strong wind; and Leroux lost his by being carried by the wind over the sea. All four accidents could have been prevented by using the gliding or rotary fall instead of the hovering fall.

Hargrave kites, broken loose, have more than once brought instruments in their interior to the ground undamaged, from a height of 1 to 2 km., by a gliding fall. The instruments were situated in the position shown in fig. 53. A man in a correspondingly greater box-kite of the same type would have been equally free from injury, the more so since the Hargrave kite, owing to its stretched fabric surface, can be steered well, and by altering the position of the centre of gravity its gliding, and especially also its landing, can be regulated.

Still better than the gliding descent is, in all probability, the rotary fall, which up to the present has never been applied. We cannot yet say definitely if a parachute depending on this principle would be safe to carry a man (although for small light plates it is the steadiest and slowest of all descents), since the fall of large plates has not yet been investigated. Sheets of paper, on account of bending, do not show regular rotation if their smallest diameter is greater than 8 cm.

Assuming that large plates also, possessing the necessary stiffness and lightness, would show a stable rotary fall, the following scheme for a rotary parachute might be possible. (Fig. 63: A is a plan, B an elevation.) A model of this form was shown at Berlin before the Conference of the International Aëronautical Commission in May 1902.

The fabric surfaces stretched on a stiff frame of cane and

wood comprise two similar halves *ff*, which are bounded on the inner side by strong rods *dd*, to which the hoop *c* is attached; this remains horizontal during the rotation of the surfaces *ff* about the long axis. The passenger sits in the hoop, not under, but in the plane of *ff*. The whole is kept rigid by struts *ss* and wires from these to the rim; *ss* and *dd* are also connected together by vertical fabric surfaces which serve to prevent a sideways gliding. Dimensions, breadth 6 metres, length 19½ metres (of which 1½ metres is in the central open space). The surfaces *ff* have an area of about 100 sq. m. Since in a rotary descent the rotary motion takes place at the expense of the translatory motion, the velocity of descent may be further diminished by the

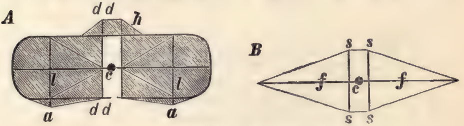

FIG. 63.—Koeppen's rotating parachute.

passenger increasing the rotation by personal work (increasing the resistance of the air by increasing the mass of air moved). An alteration of the azimuth of the movement is easily attained by raising a rib (a), parallel to the axis of rotation, on the edge of the right or left wing—see *I. A. M.*, 1901, p. 157. It is also shown in the article quoted, how, by the addition of an impulse directed obliquely upwards of the approximate magnitude of its own weight, the oblique fall of the apparatus may be converted into an equally slow horizontal movement. As to whether it will be advantageous to break up the rotating surface into several parts above or behind one another, experiment only can prove; at all events every part must be coupled together by cranks, etc., in order that they may remain parallel to one another. By moving the position of the centre of gravity *c* forwards towards *h*, we get a gliding fall instead of a rotary descent; *h* may serve as horizontal rudder or helm.

LITERATURE.

A good review of the literature up to 1899 is given by J. Vincent in the *Annuaire de l'Observatoire royale de Belgique*, 1900. The most important papers are the following:—

1. From the Blue Hill Meteorological Observatory:

(1) "Exploration of the Air by means of Kites" (Fergusson & Clayton), Cambridge, 1897; forms vol. xlii., Part I., of the *Annals of the Astronomical Observatory of Harvard College.*

(2) A number of small communications in journals.

2. "Weather Bureau, Washington." Three articles by Marvin in the *Monthly Weather Review*, November 1895, April, May, June, and July 1896, and April 1897. Also, "Instructions for Aërial Observers," Washington, 1898; not on sale.

3. "Aëronautisches Observatorium des Kgl. Preussischen Meteorologischen Instituts." (1) Assmann, articles in *Das Wetter*, 1900 and 1902. (2) Assmann and Berson, *Ergebnisse der Arbeiten des Aëronautischen Observatoriums in d. J.*, 1900 and 1901; Berlin, 1902: 1902–3; Berlin, 1904: and 1903–4; Berlin, 1905.

4. Special forms of kites:—

(1) "Military Kites for Lifting Men." Baden-Powell in the *Aëronautical Journal*, January 1899, and *Quarterly Journal of the R. Met. Soc.*, vol. xxiv., 1893.

(2) A summary relating to other forms is given in the *Illustrierte Aëronautische Mitteilungen.*

5. Hargrave's articles, mostly in the *Journal and Proceedings of the Royal Society of New South Wales*, 1893, 1895, 1896, and 1897.

6. "Drachenstation der Seewarte, Hamburg." (1) Köppen in *Prometheus*, 1901, and in the *Illustr. Aëron. Mitteil.*, October 1901. (2) Also in the *Archiv der D. Seewarte*, 1901.

7. A summary of the subject may be found in the works of (1) A. L. Rotch, *Sounding the Ocean of Air.* London, 1900. (2) J. Lecornu, *Les Cerfs-volants.* Paris, 1902.

CHAPTER VI.

ON BALLOONING.

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A.—*THE THEORETICAL PRINCIPLES OF BALLOONING.*

§ 1. THE BALLOON.

WE must distinguish between full balloons or balloons filled out tightly with gas, flabby or partially inflated balloons, "strained," and Meusnier balloons.

A full balloon ascends with constant volume, but diminishing weight, the tail being left open.

A flabby balloon ascends with constant weight and increasing volume until the gas has expanded so as to occupy the whole volume possible, after which it behaves as a full balloon.

Each type obeys certain laws. Since every full balloon becomes a flabby balloon during the descent, the laws relating to both forms come into consideration during every ascent.

The "strained" balloon, ascending with constant volume and weight, is of purely theoretical interest. We can imagine it as a full balloon closed by a safety valve, which behaves as an ordinary full balloon every time the excess interior pressure has attained such a value as to cause the valve to open.

Finally we may mention the Meusnier balloon, in which both the volume and weight alter during the vertical motion.

This we could imagine to occur if we had a double balloon covering, the air in the intervening space being compressed or allowed to flow out as desired.

§ 2. THE BUOYANCY OR LIFT.

(*a*) **Full balloons.**—Since the volume remains constant we will take the unit of volume = 1 cb. m. as the basis of our calculations.

Let p = the pressure, T = the absolute temperature = $273 + t°$ C., ρ = the density (*i.e.* under pressure p and temperature t) in kilograms per cb. m., R = the gas constant (*cf.* Chapter I., A, § 2) for air, and the corresponding letters, with dashes, for the gas, then we may write the gas equation thus:

(1*a*) $$\frac{p}{\rho} = RT,$$ and (1*b*) $$\frac{p'}{\rho'} = R'T'.$$

The specific gravity, *s*, of a gas (*cf.* Chapter I., B, § 13) is the ratio of the weights of equal volumes of the gas and air, under the same p and T.

(2) $$s = \frac{\rho'}{\rho} = \frac{R}{R'}.$$

The lift or buoyancy A is equal to the difference in the weights of the air displaced and the gas displacing it. For 1 cb. m. of gas

(3) $$A = \rho - \rho',$$

whence we obtain, applying formulæ (1*a*) and (1*b*):

$$A = \frac{p}{RT} - \frac{p'}{R'T'}.$$

Since the gas and air are at the same pressure (except in the case of "strained" or Meusnier balloons), we have

$$p = p'.$$

Remembering this, we can express the buoyancy as follows:

(4) $$A = \frac{p}{RT}\left(1 - \frac{RT}{R'T'}\right),$$

or $$A = \rho\left(1 - s\frac{T}{T'}\right).$$

The *normal buoyancy* of a balloon is the buoyancy when both the gas and air are at the same temperature, $t = 0°$ C. (T_0), and under the same pressure, $p = 760$ mm. The weight of 1 cb. m. air under these conditions

$$\rho = 1{\cdot}293 \text{ kg.},$$

and the normal buoyancy

(5) $$A_0^{760} = 1{\cdot}293\ (1 - s) \text{ kg.}$$

The specific gravity (*cf.* Table V., and Chapter I., B, § 10) of the gas depends on its degree of purity, or composition. For hydrogen, prepared by the action of sulphuric acid on iron, $s = 0{\cdot}12$.

We will take the mean values of the normal buoyancy of

1 cb. m. hydrogen = 1·1 kg.
1 cb. m. coal gas = 0·7 kg.

Under any pressure p, and at the same temperature T_0, the buoyancy is given by

(6) $$A_0^p = \frac{p}{RT_0}(1-s),$$

or $$A_0^p = \frac{760}{RT_0}\,\frac{p}{760}(1-s),$$

or $$A_0^p = \frac{A_0^{760}}{n}.$$

The "height factor" $n = \frac{760}{p}$ is the quotient of the two pressures. From the barometric height formula

$$h - h_1 = 18{,}400\,(1+\alpha t)\log_{10}\frac{760}{p},$$

or $$= 8000\,(1+\alpha t)\log\frac{760}{p},$$

the difference in all "normal" heights is determined, when we assume that the mean temperature between h and h_1 is 0°, *i.e.* $t=0$. We designate as the *normal height* of a balloon, the height which it would attain assuming that both air and gas were always at a temperature of 0°.

The height factors given in Table XV. enable the calculation to be dispensed with. The normal heights corresponding to height factors of from $n=1$ to $n=16$, or for the quotients from $\frac{760}{760}$ to $\frac{760}{47 \cdot 5}$, are given in the Table.

Calculation of the normal height of a balloon.—If the volume of the balloon = V cb. m., and the total weight of the balloon = G kg., a position of equilibrium is attained when

$$A_0^p\,V = G.$$

Now $$A_0^p = \frac{A_0^{760}}{n},$$

therefore (7) $$n = \frac{A_0^{760}\,V}{G},$$

and the normal height $= 18{,}400 \log n$, so that we can apply Table XV. directly.

Example 1.—$V = 1300$ cb. m., $G = 700$ kg., $A_0^{760} = 0 \cdot 7$ kg.,

$$n = \frac{0 \cdot 7 \times 1300}{700} = 1 \cdot 3,$$

whence from Table XV. the normal height = 2097 m.

If the mean temperature of the column of air were $t°$, the height reached would be increased by $0{\cdot}003665t$ or $\frac{t}{273}$ of its normal value, which may be assumed with sufficient accuracy as 0·4 per cent. per °C.

Example 2.—In the above example the mean temperature of the column of air 2097 m. high was 8° C. From this the extra height reached is

$$\frac{8 \times 2097 \times 4}{1000} = 67{\cdot}2 \text{ m.},$$

whence the total height is roughly 2154 m.

(*b*) **Flabby balloons.**—Since in this case the weight remains constant and the volume alters, we will assume as unit the unit of weight.

At any temperature and pressure 1 cb. m. of gas weighs ρ' kg., or 1 kg. occupies a volume of $\frac{1}{\rho'}$ cb. m. If the volume occupied were filled with air under the same conditions, the weight would be $\frac{\rho}{\rho_1}$ kg. The normal buoyancy of 1 kg. of the gas (the temperature of the air and gas being the same) is given by

$$(8) \qquad \left.\begin{aligned} A_0p &= \frac{\rho}{\rho'} - 1 \\ \text{or} \quad A_0p &= \frac{1}{s} - 1 \\ \text{or} \quad &= \frac{1-s}{s} \end{aligned}\right\} \text{in kg.},$$

and is therefore independent of the pressure and hence of the height.

If the balloon contains Q kg. gas its normal buoyancy

$$(9) \qquad = \frac{Q}{s}(1-s) \text{ kg.},$$

or, expressed in words, *a partially filled ascending balloon, as well as every descending balloon, moves with a constant buoyancy, so long as the temperature of the gas remains the same as that of the surrounding air.*

Determination of the height at which the balloon becomes full.—If at a height h_1 the volume of the gas occupies an m_1th part of the volume of the balloon, and we require the height h_2

at which it will occupy a volume $= \frac{1}{m_2}$ of the volume of the balloon, we find the height factor

$$n = \frac{m_1}{m_2},$$

and take from Table XV. the corresponding difference in heights $h_2 - h_1$.

Example 3.—A balloon has a volume of 1300 cb. m., and is filled with 800 cb. m. gas, how high must it ascend before it becomes full?

$$n = \frac{1300}{800} = 1{\cdot}62. \quad \text{Height difference} = 3854 \text{ m.}$$

Example 4.—The balloon has a volume of 1300 cb. m., and is filled with 800 cb. m. gas. At what height will the gas occupy a volume of 1000 cb. m.?

$$n = \frac{1000}{800} = 1{\cdot}25. \quad \text{Height} = 1782 \text{ m.}$$

We can calculate also, with the help of the height factors, how great the volume of gas will be when we descend from a height h_2 to a lower height h_1,

$$V_{h_1} = \frac{V_{h_2}}{n},$$

where n represents a new height factor formed by the quotient $\frac{n_{h_2}}{n_{h_1}}$.

Example 5.—A full balloon of 1300 cb. m. capacity sinks from a height of 3854 m. to a height of 1390 m.; what volume of gas will it contain at the lower height?

For $h_2 = 3854$ m., $n_{h_2} = 1{\cdot}62$

,, $h_1 = 1390$ m., $n_{h_1} = 1{\cdot}19$;

whence $$V_{h1} = \frac{1300}{\frac{1{\cdot}62}{1{\cdot}19}} = 955 \text{ cb. m.}$$

If the actual height factor corresponding to the particular height is not given in Table XV., it may be found by interpolation.

Example 6.—A full balloon of 1300 cb. m. capacity sinks from a height of 3854 m. to a height of 1000 m.; what volume of gas will it contain at the lower level?

$$n_{h2} = 1{\cdot}62 \text{ for } 3854 \text{ m.}$$
$$n = 1{\cdot}14 \;\;,,\;\; 1047 \;,,$$
$$n = 1{\cdot}13 \;\;,,\;\; 977 \;,,$$

$$\text{Difference} \quad 0{\cdot}01 \;\;,,\;\; 70 \;,,$$
$$0{\cdot}001 \text{ for } 7 \text{ m.}$$
$$1000 - 977 = 23 \text{ m.}$$
$$\frac{23}{7} = 3,$$

therefore the height factor for 1000 m.

$$n_{h_1} = 1{\cdot}13 + (3 \times 0{\cdot}001)$$
$$= 1{\cdot}133$$

and
$$V_{h_1} = \frac{1300}{\frac{1{\cdot}62}{1{\cdot}133}} = \frac{1300 \times 1{\cdot}133}{1{\cdot}62} = 909 \text{ cb. m.}$$

§ 3. DISTURBANCES OCCURRING IN THE POSITION OF EQUILIBRIUM.

Every balloon is in a position of equilibrium with the air surrounding it from the moment when it ceases to ascend. It is bound to remain at this height provided that no disturbances occur in the course of time to alter the equilibrium. Fighting against these disturbances of equilibrium is, however, one of the chief difficulties of the aeronaut. The causes of the disturbances are numerous. We have—

(*a*) **Disturbances depending on the material.**—The balloon material as such must be perfectly gas-tight. Leaks are particularly apt to occur at the seams, and the number of seams should be made as small as possible by using a special construction (*cf.* Chapter IV., p. 108, D. R. P. Finsterwalder).

Old material has often numerous small defects. The disturbances of the equilibrium arising from this cause cannot be ascertained during the trip. A balloon may be, however, tested for general tightness by comparing its loss of buoyancy in a given time with the loss of buoyancy on previous occasions or with the loss of buoyancy of similar balloons.

(*b*) **Alterations in the equilibrium due to disturbances made voluntarily.**—Such disturbances may be due to ballast being thrown out, or to gas being let out of the balloon. The amount of ballast which must be thrown out in order to reach

a certain position of equilibrium can be accurately determined by calculation.

Assuming that we start from the normal height h_1 attainable by the balloon, and which is determined by the height factor

$$n_1 = \frac{VA_0^{760}}{G},$$

where G comprises both the constant and variable (ballast) weight carried, then if we diminish the total weight G by throwing out a weight of ballast g', we can attain a new height h_2 given by

$$n_2 = \frac{VA_0^{760}}{G - g'}.$$

In order to ascertain what amount of ballast must be thrown out to ascend from a height h_1 to a height h_2, we form a new height factor $n = \frac{n_1}{n_2}$.

Substituting the above values we get

$$n = \frac{n_1}{n_2} = \frac{G - g'}{G} = 1 - \frac{g'}{G}, \tag{10}$$

and the distance ascended is given by

$$h_1 - h_2 = 18,400 \log\left(1 - \frac{g'}{G}\right), \tag{11}$$

or using natural logarithms

$$h_1 - h_2 = 8000 \log_e\left(1 - \frac{g'}{G}\right),$$

whence, assuming that the ballast thrown out is only a small fraction (under 10 per cent.) of the total weight, we get the fundamental formula for the action of ballast,

$$h_1 - h_2 = \Delta h = 8000 \frac{g'}{G}. \tag{12}$$

This important law relating to the action of ballast has been stated thus by Emden (*I. A. M.*, 1901, p. 80) :—

Every balloon ascends 80 *metres each time we diminish its weight by* 1 *per cent., quite independently of its volume, of its total weight, of the gas used, or of its height above the ground when the ballast is cast out.*

Thus if we know the weight g' of each bag of ballast carried, and the total weight G of the balloon before the ascent, we can easily calculate, with the aid of the above formula (12), how high the balloon will ascend each time a bag of ballast is thrown out.

The amount of gas allowed to escape in the course of a voyage cannot, of course, be accurately determined, and is of little practical importance. The theoretical investigation can be developed from the formula for the flow of gases (*cf.* Chapter I., A. § 11). The flow of gas depends, moreover, on the peculiarities of the valve, and on the time and amount it is opened, and on the specific gravity of the gas.

For a small excess pressure $p_1 - p$, Emden employed the following formula for the velocity of outflow of gas :—

$$v = a\sqrt{2 \log \frac{p_1}{p}},$$

where a represents the Newtonian velocity of sound, the value of which for air at 0° C. = 280 m./sec., while for different gases the velocity varies inversely as the square root of the density. Since $\frac{p_1}{p}$ is very nearly 1, $\log \frac{p_1}{p} = \frac{\Delta p}{p}$ where $\Delta p = p_1 - p$: hence we get the formula :

$$(13) \qquad v = \frac{396}{\sqrt{s}}\sqrt{\frac{\Delta p}{p}} \text{ m./sec.}$$

When the outflow occurs under a barometric pressure of about 730–740 mm., Emden sets $p = 10{,}000 = 100^2$ mm. water and arrives at the following practical formula :—

$$(14) \qquad v = \frac{4}{\sqrt{s}}\sqrt{\Delta p} \text{ m./sec.},$$

where Δp is the difference of pressure expressed in millimetres of water, and s is the specific gravity. At $t°$ C. we must multiply by $\sqrt{1 + at}$.

v decreases rapidly with the impurity of the gas and with the increase of rate of escape, and increases with the height. (*I. A. M.*, 1902, I.)

(*c*) **Disturbances arising from involuntary alterations in weight.**—These are due to deposits of moisture on the balloon material and their evaporation, also to differences of temperature between the gas and the displaced air.

Atmospheric deposits—dew, hoar frost, rain, sleet, hail, and snow—add a weight, which cannot be calculated, to the balloon, and one which may, under certain circumstances, stop the ascent. On the other hand, a wet balloon becomes lighter automatically in good weather, and rises steadily up to the moment when the evaporation of the deposited moisture ceases (*cf.* § 3*b*).

Deposits of moisture on the inner surface of the envelope occur in consequence of condensation taking place when the compara-

tively warm damp gas in the balloon comes into contact with the cool surface. This effect is, however, very small and of little practical importance.

Differences of temperature between the air and gas occur during all ascents, on account of the sun's radiation; they are particularly disturbing if sunshine and shadow occur intermittently.

Suppose the gas to be at a temperature Δt higher than that of the surrounding air. $\Delta t = t' - t$.

The true height of the balloon is given by

$$(15) \qquad h_{t't} = h_0 - 8000\alpha t + 8000\frac{s}{1-s} \cdot \frac{t'-t}{273+t'},$$

where h_0 is the normal height.

Since $8000\alpha = 8000 \times 0{\cdot}003665 = 29{\cdot}4$, Emden gives the following law:—

The height of every balloon alters by an amount $\pm 29{\cdot}4$ *metres* (*roughly* 30 *metres*), *whenever the temperature of the air decreases or increases* 1° C., *independently of its size, weight, gas, or height, as long as the balloon is a full one.*

The lift of the balloon alters by the following amount (see formula 12):—

$$(16) \qquad g' = \alpha t\,\mathrm{G};$$

i.e. *Every alteration in the temperature of the air of* 1° *C. alters the momentary lift of a balloon* 0·4 *per cent. in an opposite sense, independently of its size, weight, height, or gas, so long as it is full.*

The influence of radiation on the gas comes into account in the last term of formula (15). The specific gravity of the gas enters into this term. Now

$$\frac{s}{1-s} = 0{\cdot}77 \quad \text{when } s = 0{\cdot}435\text{, coal gas (in Munich),}$$
$$= 0{\cdot}136 \quad ,, \quad s = 0{\cdot}12\text{, impure hydrogen,}$$
$$= 0{\cdot}075 \quad ,, \quad s = 0{\cdot}07\text{, pure hydrogen.}$$

If we take $T = 300°$, which we may do with sufficient accuracy, we get

$$\Delta h = 20{\cdot}5\,(t'-t) \text{ for coal gas,}$$
$$= 3{\cdot}3\,(t'-t) \text{ for impure hydrogen,}$$
$$= 2\quad (t'-t) \text{ for pure hydrogen;}$$

or, expressed in words:

The height of a full balloon of any size or weight alters 20·5 *metres for coal gas balloons, or* 2–3 *metres for hydrogen balloons, at any height, whenever the temperature difference between the gas and the surrounding air alters* 1° *C.*

Referring back to the law of ballast (12), we can determine the action of the alteration of the temperature of the gas on the lift.

The increase of the lift g' is

$$(17) \qquad g' = \frac{s}{1-s} \; \frac{t'-t}{273+t'} \, G;$$

or if we set $T' = 300°$ as before, we have

$$\begin{aligned} g' &= 0{\cdot}0026 \;\; G\,(t'-t) \text{ for coal-gas balloons,} \\ &= 0{\cdot}0004 \;\; G\,(t'-t) \text{ for hydrogen balloons,} \\ &= 0{\cdot}00025 \; G\,(t'-t) \text{ for pure hydrogen balloons,} \end{aligned}$$

or expressed in words:

An alteration in the temperature of the gas of 1° *C. alters the lift of a coal-gas balloon* ¼ *per cent. and that of a hydrogen balloon* $\frac{1}{25}$ *per cent.* (*for pure hydrogen*).

§ 4. ATMOSPHERIC ELECTRICITY.

Numerous electric discharges occur from balloons on landing, and may easily become a source of danger from fire. The causes of these discharges have been investigated by *Börnstein*, *Ebert*, *Volkmann*, *Markwald*, and *de le Roi*; their researches have led to the following conclusions, to be accepted only provisionally until further researches have been carried out.

The electrical charge on a balloon may be due to any of the four following possibilities:—

1. **The friction of the envelope on the net or ground.**—The envelope becomes negatively and the net positively charged. The net rapidly loses its charge by radiation from its threads.

2. **Casting out of ballast.**—Ebert discovered that a balloon became positively charged by the friction of the outflowing sand against the outer wall of the car.

3. **Alteration in the position of the balloon** by the balloon as a whole relatively to the earth, and by the different portions of the balloon relatively to each other on landing.

The quantities of electricity present in different parts of the balloon alter relatively to one another and to the negative electricity on the earth's surface. The alterations in the temporary positions of the parts tend to alter the distribution of electricity.

In prolonged voyages in sunshine the envelope and network get dried and become worse conductors, so that high potential differences are set up, which may lead to spark discharges.

4. **Discharges from the tearing rope.**—These discharges, in the case of rubbered balloons, are plainly visible in the dark,

but are, according to present investigations, not a source of danger.

According to *Volkmann*, the balloon charges are due to the irregularity of the fall of potential; and the differences of potential between hoop, car, and valves become dangerous during rapid alterations in the fall of potential with height. The greatest danger, however, lies in the valve not being discharged before landing.

On one occasion, owing to the spark discharge, always observed at the valve, the gas caught fire with a dull report and burnt down, until the explosive mixture in the lower part of the balloon, due to the presence of air, burnt with a loud explosion, firing simultaneously the material of the balloon. The interval of time between the firing and the detonation is shorter with hydrogen than with coal-gas filling.

Precautions against spark discharges.—The method suggested by v. Sigsfeld, of painting the envelope with a weak solution of calcium chloride to render it a better conductor, has proved inefficient in sunny weather.

The use of radioactive materials, as suggested by Markwald, which make the air in the neighbourhood a conductor, has also proved worthless.

The simplest method of ensuring safety consists in having a valve line of several threads woven together with a few strands of thin copper wire, the conductivity of this rope remaining unimpaired even when the line is stretched. Before each ascent, the conductivity of the line must be tested, and the metal strands must be fastened to the metal of the valve, and the valve rope must be held in the hand (*cf.* Börnstein, *Z. f. L.*, 1893, No. 10; Tuma, *Ber. d. Wiener Akad. d. W.*, IIa. 108, 1899; Ebert, *I. A. M.*, 1900, 1901; Linke, *I. A. M.*, 1902; Börnstein, "Die Luftelektricität" in Assmann and Berson's, *Wissenschaftliche Luftfahrten*, 1900; Börnstein, "Berichte über der Möglichkeit elektrischen Entladungen," *I. A. M.*, 1903, 12; Volkmann, "Über die Bedingungen unter denen die elektrische Ladung eines Luftballons zu seiner Zündung führen kann," *I. A. M.*, 1904; Volkmann, "Über die Bedingungen unter denen die Ortsveränderung eines Ballons elektrische Ladungen auf ihm hervorbringen kann").

§ 5. THE WIND.

The direction and velocity of the horizontal flight is determined by the wind; this can only be detected by the observers in a manned balloon, when the balloon enters a stratum of air in which the wind differs in direction from the stratum surround-

ing the car, or, under certain conditions, in the neighbourhood of, and in, clouds.

Except under these circumstances the wind can only be detected by noting the continual alteration of the land below. In the heights at which a manned balloon usually travels, 1000–3000 metres, the direction of the wind generally follows the direction of the isobars. This is especially the case on entering a region of low pressure. When anticyclonic conditions prevail, and there are only weak breezes, the direction of travel is often very indefinite and frequently alters.

Columns of ascending and descending air may be traced to local causes, and form, therefore, disturbances limited in extent; these can only affect the motion of the balloon either through the loss of gas caused by the ascent of the balloon in an upward current, or by the cooling of the gas when the balloon enters into a region in which the column of air is a descending one.

§ 6. PROLONGED VOYAGES.

Prolonged voyages form the foundation for the technique of ballooning, since they necessitate the least use of material (ballast and gas), and consequently need the most careful management.

The following are fundamental rules :—

1. The inflated balloon must be held as low as possible at the ascent.
2. Keep the balloon out of the influence of the sun's radiation as long as possible.
3. Remain floating as long as possible on cloud strata.
4. Prevent all voluntary loss of gas through opening valves.
5. Avoid all unnecessary loss of ballast.
6. Keep the balloon quite full.

By following these rules the balloon continues in an ascending straight line, inclined at a lesser or greater angle, up to the maximum height (until the materials are exhausted), given by the formula (12).

The saving of material may be still greater if the following recommendations due to Voyer (*R. d. l'Aé.*, tome viii., 1901) are adopted in the construction—

1. Precautions against deposits of water :
   (*a*) A better-arranged form for the upper hemisphere of the balloon so that the water may drain off.
   (*b*) A roof above the valve, to shelter it from rain.
   (*c*) A rain-dripping band around the equator.

(*d*) The protection of the net by a net covering of smooth waterproof material (*cf.* Graf v. Zeppelin's Air-ship).

2. Precautions against disturbances of equilibrium by the sun's radiation:
   (*a*) Air ventilation between the balloon and net covering (*cf.* Graf v. Zeppelin's Air-ship).
   (*b*) Painting the net covering white.
3. Precautions for keeping the balloon full:
   (*a*) Construction of balloon with *ballonet* and valve (*cf.* Chapter IV., § 26).

Many causes tending to shorten the voyage may be avoided by starting at sunset and travelling in the night.

Unge of Stockholm had a balloon built especially designed for long voyages and embodying the above suggestions. He died on April 23rd, 1904, before the trials were completed. (*I. A. M.*, 1902 and 1904.)

The following list of recommendations, in part adopted and in part proposed, for aëronautical scientific work, has been drawn up by Voyer:—

1. Lifting screws.
2. Heating the balloon gas.
3. Combination with a Montgolfier.
4. A *ballonet* with warm air.
5. Auxiliary balloons full of gas (*compensateur à gaz*), and auxiliary balloons full of air (*compensateur à air*).
6. A *ballonet* with steam.

We are led to the conclusion that, of these, only the following suggestions are practicable:—

1. The *ballonet* with warm air (4).
2. Lifting screws (1).
3. Warming the gas by steam.

§ 7. BEHAVIOUR OF SIMILAR BALLOONS INFLATED DIFFERENTLY.

Let the different lifting powers be A_0^{760} and a_0^{760}. Then the normal heights are given by the corresponding height factors n_1 and n_2 from the equations:

$$(18) \qquad n_1 = \frac{VA_0^{760}}{G}; \qquad n_2 = \frac{Va_0^{760}}{G}.$$

The difference of the two heights may be found by forming a new height factor $n = n_1/n_2$, which is given by

$$n = \frac{A_0^{760}}{a_0^{760}}.$$

Whence the difference in the maximum heights

$$(19) \qquad \Delta h = 18{,}400 \log n = 18{,}400 \log \frac{A_0^{760}}{a_0^{760}}.$$

The difference in the altitudes reached by equal and equally loaded balloons inflated with different gases depends only on the nature of the gases employed and not on the sizes or weights of the balloons (neglecting temperature influences).

Example 7.— $V = 1300$ cb. m., $G = 700$ kg.,
Hydrogen, $s = 0{\cdot}12$, $A_0^{760} = 1{\cdot}14$ kg.,
Coal gas, $s = 0{\cdot}435$, $a_0^{760} = 0{\cdot}73$ kg.,

$$n = \frac{1{\cdot}14}{0{\cdot}73} = 1{\cdot}562, \text{ corresponding to } \Delta h = 3563 \text{ m.};$$

that is, any hydrogen balloon will ascend 3560 m. higher than an exactly similar and equally loaded coal-gas balloon.

For chemically pure hydrogen

$$s = 0{\cdot}069, \qquad A_0^{760} = 1{\cdot}2,$$
$$n = \frac{1{\cdot}2}{0{\cdot}73} = 1{\cdot}642, \qquad \Delta h = 3970 \text{ m.},$$

so that the difference in height for pure hydrogen = 3970 m.

§ 8. THE BEHAVIOUR OF DIFFERENT-SIZED BALLOONS INFLATED WITH THE SAME GAS, AND EQUALLY LOADED.

Let the contents be V_1 and V_2. The maximum heights are given by the height factors

$$n_1 = \frac{V_1 A_0^{760}}{G}; \qquad n_2 = \frac{V_2 A_0^{760}}{G}.$$

The difference in height can be obtained from the new height factor $n = \frac{n_1}{n_2} = \frac{V_1}{V_2}$; whence

$$h_1 - h_2 = 18{,}400 \log n = 18{,}400 \log \frac{V_1}{V_2}.$$

The difference in the altitudes reached by balloons unequal in size but equal in weight and inflated with the same gas, depends only on the volumes, and not on the weight or nature of the gas (neglecting temperature effects).

Example 8.— $V_1 = 1500$, $V_2 = 1300$,

$$n = \frac{1500}{1300} = 1{\cdot}154, \text{ whence } \Delta h = 1145 \text{ m.},$$

so that the balloon of 1500 cb. m. capacity would always rise 1145 m. above that of 1300 cb. m. capacity (equally loaded).

§ 9. THE LIMITING HEIGHT OF A BALLOON.

The limiting height of a balloon is determined theoretically from its normal height as deduced from its height factor n:

$$n = \frac{VA}{G}.$$

If different balloons are required to rise to the same height, n must be made the same for each, by suitable alterations in G.

If the balloons are filled with the same gas, the relative heights are determined by the ratio $\frac{V}{G}$.

The influence of temperature is the same for all balloons filled with the same gas. We may note that, using different gases, balloons inflated with those having the lowest specific gravity will be least influenced by the sun's radiation (*cf.* formula 17).

§ 10. THE LANDING.

A weight of ballast depending upon the height and the temperature difference must be thrown out in order to avoid bumping and make the landing free from danger.

Emden, who first propounded a clear theory in connection with the landing (*I. A. M.*, 1900, p. 86), distinguishes between brake-ballast, used to decrease the rate of descent, and landing-ballast, used to effect the landing.

The brake-ballast may be carried in the form of sand and water, or of a trail rope.

If we substitute in formula (8) the values for ρ and ρ' from formulæ (1*a*) and (1*b*), we obtain:

$$A_0 p = \frac{\frac{p}{RT}}{\frac{p}{R'T'}} - 1 = \frac{p}{RT} \cdot \frac{R'T'}{p} - 1.$$

Now $\frac{R'}{R} = \frac{1}{s}$, and $\frac{T'}{T} = 1 + \alpha . \Delta t$, with a sufficient degree of accuracy, where $\Delta t = t' - t$, *i.e.* the difference of temperature between the gas and air. Substituting these values we obtain the lift of 1 kilogram of the gas

$$= \frac{1 + \alpha \Delta t}{s} - 1 = \frac{1 - s}{s} + \frac{1}{s} \alpha \Delta t.$$

The balloon contains Q kg. gas: the lift of the balloon is therefore

$$(20) \qquad \frac{Q}{s}(1-s)+\alpha\,.\,\frac{Q}{s}\Delta t \text{ kg.}$$

This lift, at the end of the ascent with a temperature difference $\overline{\Delta t}$, is equal to the weight of the balloon G, as given by the formula:

$$(\mathrm{I}) \qquad \frac{Q}{s}(1-s)+\alpha\,.\,\frac{Q}{s}\overline{\Delta t}=G.$$

If we imagine the balloon drawn down to the ground, Q and s are scarcely altered, if the mouth is closed, whereas the difference of temperature $\underline{\Delta t}$ increases, and alters therefore the value of the lift by an amount $\pm X$. We get then the relation:

$$(\mathrm{II}) \qquad \frac{Q}{s}(1-s)+\frac{\alpha Q}{s}\underline{\Delta t}=G-X,$$

where X is the brake ballast, of which the balloon must be lightened; this is obtained by subtracting the formula II from I. We have then:

$$(21) \qquad X=\alpha\frac{Q}{s}(\overline{\Delta t}-\underline{\Delta t}),$$

or

$$X=\alpha\frac{Q}{s}[(\overline{t'}-\overline{t})-(\underline{t'}-\underline{t})],$$

or

$$X=\alpha\frac{Q}{s}[(\overline{t'}-\underline{t'})-(\overline{t}-\underline{t})].$$

Whence we can derive the following rules:—

1. *If equally large balloons attain the same maximum height, then if the differences of temperatures above and below are the same, the amount of brake ballast which must be thrown out is independent of the kind of gas employed to inflate the balloons.*

2. *If the temperature differences are the same above and below, the same balloon requires less ballast on landing the greater the height from which it descends.*

Example 9.—The weight of air $\frac{Q}{s}$ can be calculated, knowing the volume of the balloon V.

V cb. m. air at 760 mm. pressure weigh 1·293 V kg. The maximum height h is given in the table of height factors n:

$$\frac{Q}{s}\text{, at a height } h, =\frac{V\,1{\cdot}293}{n}\text{ kg.}$$

Suppose we have a balloon of $V = 1300$ cb. m.;
At 760 mm. pressure it displaces

$$1300 \times 1{\cdot}293 = 1680 \text{ kg. air.}$$

At a height of 4000 m., $n = 1{\cdot}65$.
The same balloon displaces at this height

$$\frac{1680}{1{\cdot}65} = 1020 \text{ kg. air.}$$

The term $\alpha \dfrac{Q}{s}$ has therefore the value

$$\frac{1020}{273} \text{ or } 0{\cdot}003665 \times 1020 = 3{\cdot}7 \text{ kg.};$$

that is, the brake ballast necessary in the foregoing case is 3·7 kg. for every degree of alteration in temperature between the gas and air.

Unfortunately the temperature term, which is the cause of considerable variations, cannot be taken into account, since only the temperatures of the air $\bar{t}$ and $\underline{t}$ are known, very few researches on the alterations in the temperature of the gas having been carried out up to the present time. In a forty-six-hour experimental journey on the 2nd, 3rd and 4th of November 1901, von Sigsfeld found, using an electric thermometer of Prof. Klingenberg's, that, at that time of the year, no difference of temperature existed between the gas and the open air at 3 P.M. From that hour onwards the temperature of the gas fell more rapidly than that of the air, while, naturally, at sunrise the temperature of the gas rose more quickly than that of the air owing to radiation from the sun. On the 4th November, at 10 A.M., the temperature of the gas was 13° C. below that of the air.

On the 11th October 1894, between 1 and 2 P.M., at a height of 1400 metres, and just above a layer of cloud, Hermite and Besançon found the temperature of the gas to be 46–47° C., while the temperature of the air was between 13° and 16°. They also found a difference of temperature of 25° to 27° at a height of from 2300 to 2400 metres on a voyage on the 21st November 1897 between 1.30 and 3 P.M.

On the voyage of the 11th October 1894 the temperature difference decreased in a very short time from 34° above the clouds to 21° on landing.

The above examples will serve to show the importance of further investigations in this direction.

Emden gives the following formula for the influence of alterations in the temperature of the gas on balloons becoming

flabby. If the temperature of the gas is suddenly decreased by an amount Δt°, then the weight of ballast which must be thrown out to balance its influence is

$$X = \alpha \frac{Q}{s} \Delta t \text{ kg.} \tag{22}$$

For every degree of fall of temperature of the gas, the buoyancy of a flabby balloon alters by an amount $=0{\cdot}4$ *per cent. of the weight of air displaced, independently of the nature of the gas used. Equal decrements of temperatures have a smaller effect the higher the balloon is when they occur.*

The landing ballast is kept as a reserve to be used only at the last moment, if difficulties arise owing to the nature of the ground or the strength of the wind. The quantity necessary cannot, therefore, be considered from a theoretical standpoint.

B.—*THE PRACTICE OF BALLOONING.*

§ 1. THE CONDUCTOR'S DUTY.

Investigation of the materials, more especially of the envelope of the balloon, the valves, and the tearing arrangements, to test their fitness for use.

Every conductor should be made fully aware of his responsibility for these being in perfect order.

The ropes must lie clear, and the valve and tearing lines must on no account be twisted.

Small holes are easy to stop up in a varnished balloon; patches are sewn over them, and at least two coats of varnish applied.

In rubbered balloons the material near the hole must be cleaned, and a patch of the prepared material stuck on with rubber solution.

The instruments must be collected together, including barometer, barograph, ventilated psychrometer, clock, compass needle, maps (a general map and maps on a scale of at least 1 : 500,000), railway time-table, labels, telegraph forms, passports (necessary only in Russia), knife with several blades, a large crossbar for the valve line, padlocks for the basket and the instrument compartments.

The ballast, when of sand, must be dry and free from stones. Iron filings must be sieved. Water ballast is mixed with glycerine, in order to prevent freezing.

§ 2. INFLATING.

1. **Preparatory arrangements.**—Inform the gas manufacturers. Clear the ground on the filling station and barricade it, if necessary. Lay out the ground coverings, connect the hose on to the gas pipes. Fill the sand bags and place them in position.

2. **The inflation.**—Lay the folded balloon on the sheet in such a manner that the tail faces the gas-hose.

(a) *Circular method of inflation.*—Unfold the material so that it forms a circle with the valve in the middle, pull the tail so far towards the gas-pipe that it lies on the periphery of the circle covered by the balloon material. Connect the tail and gas-hose by means of a suitable socket, after the valve and tearing lines have been drawn out through the socket. Fasten the ring of the tearing line in the safety link. Make certain that the tearing line and valve line lie perfectly clear of the valve. Fasten in the valve. Lay the net over the whole, and spread it out regularly. Distribute and hook on the sand-bags (with the points outwards) around the balloon.

After the helpers have been distributed around the balloon, one at least holding on to the tail, open the gas-pipes. The sand-bags are hooked on to lower rows of meshes as the filling proceeds, on orders to that effect being given. As soon as the balloon is half full the number of bags of ballast hung on must be doubled.

See that the meshes of the net are kept in their proper positions during the inflation, and that all creases are prevented in the balloon material.

When the inflation is complete, hook on the hoop and car. The latter must be ready, fitted up and provided with ballast. Fasten the trail rope on the hoop beneath the tearing seam. Lay out the rope in the direction of the wind, or, where space is limited, in a coil. As soon as the balloon is full, draw away the gas-pipe and bind up the filling-hose. Again see that the valve and tearing lines are in their right positions. Entrust the ends of the lines to a qualified person. Fasten up the tail in such a manner that it may be easily opened before the ascent.

Hook the sand-bags on to the goose's neck and paying-out rope. Place the car under the balloon. Allow the balloon to rise until the hoop is above the ground. Gradually hook off the ballast bags from the ring and place them in the car. Hold on to the edge of the car and the trail-rope.

Although the inflating proceeds in calm weather, or in a balloon hall, without difficulty, skilful direction and experienced assistants are required when inflating in an open space in windy weather.

(b) *Method of inflating laying the balloon out at full length* (*en baleine*).—This method is advantageous in still weather, where few assistants are available, for large balloons, or when several balloons are to be inflated simultaneously.

The principal point is to fold the balloon gores in such a manner that they unfold themselves as the gas flows into the balloon. The strip for tearing must lie at the top.

The balloon is laid on the sheet as in method (*a*), except that only a small circle of materials is laid around the valve-hole. The valve and tearing lines must be drawn through the balloon by a man creeping through it, and laid to the right and left in gores as far apart as possible. When the tail has been connected to the filling hose, and the valve placed in position, a whole row of strings are laid at certain distances apart around the balloon material, and fastened together with loops. Above this the net is drawn, fastened, and spread out. Hook on the ballast bags around the circle and along the gores.

In this method the long section of balloon forms, as it were, a continuation of the hose pipe. The gore being filled becomes larger and larger, raising the cross bands, and it is drawn towards the tail. Otherwise the inflation proceeds as in (*a*).

In letting the balloon go, as many assistants are required as before.

(c) *Balloons* with a large lifting power, very large balloons, and also sounding balloons, require special holding nets or ropes for the inflating, fastened to earth anchors distributed around the filling ground. The arrangements are made in such a manner that each holding line can be set free after the car of the balloon has been weighted.

(d) *Kite-balloons.*—Turn the valve towards the wind, stretch out the balloon on the sheet. The rigging is arranged regularly on either side. Proceed as in (*a*). (*Cf. Exerzier-Reglement für Luftschiffer*, Berlin, 1903 ; v. Tschudi, *Der Unterricht des Luftschiffers*, Berlin, 1905).

(e) *Hot-air balloons* (Montgolfiers).—Calm weather is necessary. Hang the envelope between two masts over the oven. The masts must be comparatively strong and arranged at a suitable height and distance apart.

Trusses of straw or vine-cuttings are used as the fuel for heating the air, though recently special ovens with petroleum fires have been introduced.

(f) *Stiff balloons and air-ships.*—The following four methods of inflating are in use:—

(*a*) The metal balloon is filled with water, which is then displaced by gas—only applicable to very small balloons.

(*b*) Lead in the gas to the highest point of the balloon by

means of a tube. Even when inflated very carefully, a certain amount of air remains mixed with the gas (Marey Monge, 1845, *Études sur l'aérostation*, Paris, 1847).

(*c*) Fill the space with a fabric balloon inflated with air. Press out this air balloon by passing gas into the envelope of the stiff balloon. In drawing out the auxiliary air balloon, air enters the stiff envelope and spoils the gas (Schwarz, Berlin, 1900).

(*d*) Inflate an inner fabric balloon, which fits the stiff envelope perfectly (Graf v. Zeppelin, 1900). In inflating balloons from cylinders of gas, a number of these are placed together on a suitable waggon. The common tube network of the system is connected by means of a rubber hose with the central vessel and thence led to the balloon.

§ 3. WEIGHING AND LETTING GO.

The conductor and passengers take their places in the car. The tearing line and valve line are made fast to the car or to a car rope, and the tail rope is hung through the hoop and fastened with double knots. The trail-rope is fastened to the car. Ballast is removed from the car until the balloon will lift it. The tail must then be opened and the trail-rope laid out. Again glance through the mouth to see that the tearing and valve lines hang correctly ; place a ballast bag by the side of the conductor and each passenger. The position of the conductor should be such that he can see the trail-rope and the barometer. The command, "Let go!" is most conveniently given by a person left behind in charge on the filling ground.

The conductor takes care that the trail-rope is raised by the balloon, and compensates every tendency to descend by a judicial expenditure of ballast.

In stormy weather the balloon must be given considerably greater lift, and must be let go during any momentary calm in the storm.

A very long air-ship (Graf v. Zeppelin) is most conveniently weighed by fastening it to two dynamometers anchored to the earth, which give an exact measurement of the lift due to the two halves of the air-ship.

§ 4. THE VOYAGE.

The general rules relating to the voyage which the conductor must follow are considered at length in division A ; for the

laws relating to balloon travelling in the German Empire, *cf.* *I. A. M.*, 1901, Nos. 3 and 4; *Bürgliches Gesetzbuch*, §§ 224, 227–229, 254, 366, 367, 823, 831, 842–845, 847.

Since there is always a possibility that the descent must be made in a foreign state, every balloon conductor should possess evidence of belonging to some recognised aeronautical club or station, which is of international standing, or a conductor's pass.

For the recommendations relating to the granting of these "passes," see "Commission Permanente Internationale d'Aéronautique, Sous Commission du brevet d'aéronaute Rapport," 10th October 1901 (*I. A. M.*, 1902, p. 64).

During the voyage an itinerary should be taken (*cf.* von Tschudi, *Instruktion für die Ballonführer*, Berlin, 1905); the time, place, barometric height, temperature, wet and dry bulb thermometer readings, ballast thrown out, use of valve, balloon cards thrown out, should be recorded. As special phenomena the following should be noted:—Atmospheric pictures (cloud photography) and processes, phenomena relating to the balloon materials, observations on the flight of birds (*cf.* v. Lucanus, *Journal für Ornithologie*, January 1902), on sounds heard, the influence of the nature of the land on the flight of the balloon, and on the orientation during the voyage. Instruct the passengers on their behaviour on landing. Before landing, descend until the trail-rope is on the ground. Prevent the rope going over houses on account of the damage thus caused, and the danger to persons below, and prevent it passing over railway tracks for your own sake, and over telegraph wires and trees, since it easily becomes entangled, especially in the latter.

Choose the landing-place with reference to the availability of the necessary personal assistance, also choose a clear ground and one in a convenient locality for the return journey (when possible).

Passengers must obey implicitly the instructions of the conductor.

§ 5. THE LANDING.

Preparations.—Pack all fragile instruments, glasses, and bottles; place the remaining bags of ballast on the trail-rope side; fasten up the valve line; hold the tearing-line; bind both to the basket-work close to the position of the conductor, who should stand on the trail-rope side of the car; place the ballast close at hand.

When low above the ground or during the trailing voyage, free the tearing line from the hoop (*cf.* fig. 16*c*). Diminish the buoyancy as desirable by opening the valve for short periods. Prevent the velocity of descent becoming too great, according as

the landing-place is near at hand or far distant, by an energetic discharge of ballast (shake out, but do not throw out whole bags) after the trail-rope has been arranged, or by a gradual discharge of ballast during the course of the descent. Look out for alterations in the direction of flight before the landing.

Tear the envelope open as soon as favourable landing conditions occur, some 15 to 20 metres above the ground or after the first bump. Hold fast to the car on the trail-rope side; bend the legs before a bump occurs to reduce the shock to the system. In a calm atmosphere it is possible to land without tearing, and by a proper use of ballast without bumping.

In a strong wind the horizontal velocity of the balloon causes a more or less vigorous bumping, during which the car usually topples over on the trail-rope side. If a dragging voyage begin, which only occurs when the tearing arrangements do not act, or when the wind forms a sail of the empty balloon, one protects oneself by holding on to the grips inside the car, and by taking precautions against a sudden loss of balance and against being thrown out by the car turning over. Further care is taken that the head shall never come on the trail-rope side of the car.

It is the duty of every conductor in critical moments to set an example of coolness and cold-bloodedness to the passengers, and to warn them at the right moment of any danger, and to do all in his power with the materials at hand to end the dragging journey as quickly as possible.

After landing.—Determine the time and place; keep at a distance persons with cigars, pipes, etc.; seek out persons who are willing to offer assistance (for instructions in foreign languages see v. Tschudi, *Instruktion für die Ballonführer*, Berlin, 1905).

Unfasten the car and hoop; free the trail-rope and any other ropes; lay clear the paying-out ropes; take off the valves (pack the valve screws with the nuts in an empty sand-bag); straighten out the envelope (do not tread on it with boots or shoes) and roll the two sides together loosely, so that the valve ring lies at one end and the tail ring at the other. When sufficient intelligent helpers are at hand, fold the balloon smoothly gore by gore.

After this roll up the envelope from the valve ring end into a packet; lay the valve, tearing, and tail ropes on the top; spread out the cloth for packing near the envelope, and draw the envelope on to it, fastening it up in a convenient parcel; draw the net lengthwise, roll up, and bind into a suitable bundle.

Clean the car; empty the ballast bags; pack them along with fasteners and knives into the car, placing over them the trail-rope, net, hoop, and valve; secure the car.

If no packing cloth is carried for the envelope, pack this

also in the car. In cars with seats lay the net and cords underneath, otherwise lay on the top with the hoop and valve above. Bind everything firmly together with the car ropes; order waggons; write out consignments; instruct the carrier as to the handling of the balloon; do not put the car on the top of the envelope; do not allow the waggon wheels to rub against the envelope; all instruments and charts should be carried by the aeronaut himself.

Enquire about damage to fields and compensation. Obtain at once a written statement.

Reward the people assisting, obtaining receipts. Pay for the carriage of the materials to the station.

Forward telegrams *re* the success of the voyage.

§ 6. BALLOON SPORTS.

Conditions.—1. A problem whose solution is possible. 2. An honour or monetary reward for those who solve the problem best. 3. Carrying recording instruments accurately tested beforehand, and again overhauled before the voyage.

The sport depends on the skill of the aeronaut and the quality of his materials. Competitions may take place between aeronauts alone or between aeronauts and cyclists or motor cars.

A. **For pure balloon sport**, the following main problems may be distinguished—requiring very different kinds of skill from the aeronauts (*cf. Illustrierte Mitteilungen des Oberrheinschen Vereins für Luftschiffahrt*, 1897, p. 55; Moedebeck, *Der Sport in der Luftschiffahrt*).

The *Fédération Aéronautique Internationale*, founded in Paris on Oct. 14, 1905, has laid down certain rules and regulations governing all such sport, which are recommended for the acceptance of all Aeronautical Clubs, and among other events, govern the annual competition for the Gordon-Bennet prize.

1. *Time competitions.*—To remain in the air as long as possible (*cf.* Chapter VI., A, § 6): determine for the handicapping the size of least balloon taking part in the competition and take its buoyancy as normal. The extra ballast for larger balloons is furnished in sealed bags, and must be returned unopened after the descent (*cf.* Chapter VI., A, § 9).

2. *Distance competitions.*—To travel as far as possible without a break of journey. Use favourable air currents.

3. *Speed competitions.*—To cover a certain distance in the direction of the wind in the shortest possible time, a maximum height-limit being fixed. In the handicap limit the height not to be exceeded during the trip to the maximum height possible for the smallest balloon, since the velocity of the wind usually increases with the height.

4. *Time-height competitions* (which must be distinguished from greatest height competitions, which possess only a meteorological and scientific interest and must be excluded from sport). To travel as long as possible at a certain previously arranged height. Handicap according to the smallest competing balloon. Balloons with *ballonets* and fans are best suited for this purpose (*cf.* Chapter IV., § 26).

5. *Object competitions.*—To land as near as possible to a place previously fixed upon, lying approximately in the direction of the wind, or to the landing place of a balloon previously sent aloft.

6. *Trail competitions.*—Low voyages with a rope trailing on the ground. Can be combined with the competitions 1, 2 and 5, but are difficult to carry out in cultivated regions on account of the damage which is liable to be caused by the trail-rope.

7. *Marine competitions.*—A trailing voyage over the sea using driving anchors and buoys (*cf.* Chapter IV., § 22). Inland seas with islands are suitable places for this amusement. Larger seas (such as the Irish Sea) should be used for practising.

8. *Travelling competitions.* — Using all means, including breaks of journey, in order to reach a given place by balloon. The conditions may be very varied, the time taken, the breaks of journey allowed, re-inflations of the balloon all being taken into account.

Air-ships would prove invaluable in these competitions, and this form of sport must undoubtedly will lead to their further development.

B. **Balloon sports in conjunction with other sports.**

1. *The most rapid fulfilment of an errand* with the help of cyclists carried with the balloon.

2. *Following the balloon with cyclists.*—A prize for the first cyclist to reach the landing place.

3. *Carrying a motor-cyclist* to fulfil a certain purpose, with motor-cyclist following in the wake of the balloon with a view to his capture.

4. *Carrying a cyclist or motor-cyclist*, and following with transport motors for the balloon materials. The problem is the quickest return of the transport with the allotted balloon.

Cyclists or motor-cyclists serve to seek out and guide the transport motors to the landing place.

5. *Carrying a photographer.* — Taking certain views or generally for the best views taken.

6. *Carrying carrier pigeons.*—Forwarding a continuous record of the progress of the voyage by means of carrier pigeons.

7. *Carrying a Marconi's receiver.*—Continuous communication with the aeronaut by means of wireless telegraphy. *Object.*—Delivery of the news of the voyage during the journey or at the end station.

§ 7. COMPUTATION OF RESULTS OF BALLOON VOYAGES.

In connection with the methods of working out the results of balloon voyages, it is to be noted that the particular purpose of the voyage must always be kept in mind when working up the observations. This applies more particularly to the observations taken by the conductor in connection with the object of the trip. The itinerary must therefore be worked out for a definite purpose, and furnished with the necessary diagrams.

The same scale for the diagrams of the voyage, and for similar voyages with which it is to be compared, should be used.

KINDS OF DIAGRAMS.

Name of diagram.	Abscissæ.	Ordinates.
A. **Time diagrams.**—		
1. Distance-time, ...	Time.	Distance.
2. Height-time, ...	Time.	Height.
3. Ballast-time, ...	Time.	Ballast.
4. Sunshine-time, ...	Time.	Sunshine.
B. **Distance diagrams.**—		
5. Time-distance, ...	Distance.	Time.
6. Height-distance, ...	Distance.	Height.
7. Ballast-distance,[1] . . .	Distance.	Ballast.
8. Sunshine-distance,[2] . .	Distance.	Sunshine.

Phenomena occurring at intervals—for example, precipitations—should be marked on the diagrams where they occur, in point of view of time or distance.

Besides these it is always advisable to trace the projection of the path of the balloon on the earth on a suitable map.

For adjudicating balloon sports the following diagrams should be demanded :—

1. *Time competitions.*—Nos. 3, 4, 2. Plan of the line of route, with observations on the nature of the land traversed.

2. *Distance competitions.*—Nos. 5, 6, 7, 8. Plan of the line of route as above.

3. *Speed competitions.*—Nos. 1, 2, 6, 4. Plan of the line of route as above.

[1] The amount of ballast required for landing should be left out of account.

[2] The ordinate-axis is conveniently divided as follows :—Bright, cloud layer ; sun shining through cloud ; feeble veil-like clouds ; bright sunshine. Readings on a black bulb thermometer are better.

4. *Time-height competitions.*—Nos. 2, 3, 6.

5. *Object competitions.*—Nos. 1, 5, 6, 7, 8. Plan of the line of route with the addition of the wind directions on the ground and observations of clouds, of the flight of the cards thrown out, and of other balloons.

6. *Trail competitions.*—Nos. 5 and 6. Height limited by trail-rope; the diagram should show, therefore, the ballast-distance curve for ballast carried. Nos. 7 and 8 for ballast cast out. Plan as above.

7. *Marine competitions.*—As for trail competitions, but with the addition of the wind direction as given by the driving anchor, and the leeway due to sea currents.

8. *Travelling competitions.*—Details concerning the general conditions, including the details of the ascent, journey, and landing. Add the necessary diagrams (as above). (*Cf.* also Hoernes, *Über Ballonbeobachtungen und deren graphische Darstellung mit besonderer Berücksichtigung meteorologischer Verhältnisse*, etc., Vienna, 1892.)

With reference to the competitions mentioned in § 6, B, the corresponding details and diagrams are necessary.

It is evident that such computations, carried out in a systematic manner, form splendid material for the education of the young balloon conductor.

CHAPTER VII.

BALLOON PHOTOGRAPHY.

By Dr A. MIETHE,

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§ 1. GENERAL CONSIDERATIONS.

Since a general participation in aeronautical ascents is not practicable at the present day, photography serves a useful purpose in interesting the general public in ballooning, bringing down, as it does, authentic records from every height in the atmosphere. To the aeronaut himself, however, and to all those who are interested in the scientific problems connected with aerial voyages, photographs taken on board the balloon serve one of the most useful purposes in aerostatics. These facts are so obvious that they were recognised at a very early date, and experiments on photography from the car of a balloon are almost as old as the art of photography itself. It is, however, only in the most recent times that photography has been recognised as indispensable, and the photographic outfit as amongst the most important apparatus carried by the aeronaut.

Apart from the possibility of making photographic exposures from the balloon, attempts have also been made to replace the balloon by other vehicles, more especially by kites, for the purpose of obtaining aerial photographs. As far as is known, these experiments have not been carried beyond a form of recreation, as is readily understood, if we remember that that which makes a photograph of value is the careful focussing of the object by the operator. A photograph taken haphazard from a kite or from a balloon without an aeronaut, will be, in general, worthless. We will, therefore, not consider further such applications, but confine ourselves to a short account of the means and methods of photography in so far as they are of importance to the aeronaut for scientific purposes.

§ 2. THE APPARATUS.

The photographic apparatus consists essentially of the camera and stand. The stands used by aeronauts will naturally differ essentially from those used for exposures on the flat earth. They must be adapted to the conditions holding on board the car, and are, as a matter of fact, frequently entirely dispensed with. Since it is one of the principal conditions for every exposure, however rapidly the instantaneous shutter may operate, that the apparatus itself should stand as still as possible, it is best to have the camera firmly attached to the car, either by being let into the floor or by fastening it by means of strong universal joints. The hand-camera may, however, be of great service in the balloon; its infinite freedom of movement affording the possibility of taking exposures in every desired direction within a very short interval of time. The photographs so taken will differ the less from those taken with the fixed apparatus in point of distinctness the steadier the operator holds the camera and the better he chooses a moment of relative stillness, during which neither the rotational movement of the balloon about its vertical axis, nor the swinging of a captive balloon, detracts from the sharpness of the image. As far as concerns the camera itself, not much need be said. The aeronaut's camera will not differ essentially from the ordinary tourist's camera, although, of course, certain conditions must be fulfilled on board the air-ship which are not so necessary in cameras for use on the earth. It is of the highest importance to have a camera as strongly and solidly built as possible. Leather cameras are very liable to get damaged in the limited space on an air-ship, rendering them no longer properly light-tight. Solid cameras offer, consequently, an advantage in this respect. It is of the greatest importance to be able to make several exposures very quickly one after the other. For this purpose it is at least necessary to have a large number of plate holders, but better to have a magazine arrangement, such as is often attached to hand-cameras. With such magazine arrangements, if properly constructed, the plates may be changed with extreme rapidity, and in some forms of apparatus (*e.g.* Krügener's Hand-Camera) so rapidly as to allow 12 exposures to be made within 30 seconds. The magazine arrangement must, under all circumstances, be so constructed that its working cannot be interfered with by the sand used as ballast. Consequently it is not the delicately built change-holders that are most serviceable, but only such changing arrangements as work by the complete turning of the plate.

§ 3. THE SHUTTER.

Concerning the instantaneous shutter only a slit stop should be employed on board a balloon. The slit stop offers, on the one hand, the great advantage that the time of exposure can be varied within very considerable limits with safety, and, on the other hand, the advantage that the sensitive plate is not illuminated all at one time, the flash travelling, as it were, rapidly across it, so that a small movement of the camera, caused by the unsteadiness of the support, affects the result least; lastly, the slit stop has the great advantage in itself that it is protected from all damage inside the camera, and, moreover, on account of its simple construction, guarantees a certain result, even in the hands of a person not thoroughly trained in the art of photography. The construction of the slit stop has been enormously improved in recent times, and the rapid and certain regulation of the breadth of the slit is, above all things, a great advantage in the modern applications of this art, whilst in the older arrangements (circular stop) this regulation left much to be desired. Among the best slit stops are Stegemann's Double Roller Stop, and the much simpler and extremely effective slit stop of Goltz & Breuthmann of Berlin.

§ 4. THE LENS.

The most important question as regards the photographic apparatus for balloon work is the choice of the lens to be used. It may be answered if we consider carefully the conditions under which it is to be used. Since on board the balloon only instantaneous photographs will be taken, it is obvious that we can deal only with strongly lighted subjects; on the other hand, we must remember that the light as observed from the car is comparatively very strong, owing to the intense action of the sun on the earth's surface, and the great distance of the nearest objects. If we take the smallest aperture for ordinary instantaneous exposures as *f*/12, then on board the car a still smaller aperture can be taken, especially in cloud photography, where an extraordinarily small fraction of the focal distance—*f*/20 or even *f*/36—can be taken. In spite of this, it is better to employ an objective which may be used both for instantaneous work and also for very short exposures in an unfavourable light, as in twilight, or when the sun is very low on the horizon. On the other hand, we require the objective to give as large as possible a picture with the greatest possible distinctness of outline, also with relatively strong illumination, and at the same time the photographs must give exactly the central per-

spective, so that they may be used for the purposes of photographic survey work. All these conditions are fulfilled in the widest sense by the "Anastigmate" series, by Steinheil's Rapid-Anteplanate, and by the Aplanate and all objectives of a similar type (Euryskope, etc.).

The "Anastigmate" combine in the highest degree the desirable properties of all these lenses. In choosing between these lenses several points must be considered. This series work usually with a full opening of at least *f*/8, and give with this stop a field of view on the plate whose longest dimension is at least equal to the focal length. In balloon work, however, it frequently happens that the depicted objects must not be shown on too small a scale, in order that details may be studied even from great heights, and longer focal lengths are often necessary. A focal length of 25–28 cms. is most convenient, therefore, for the usual size of plate, 13 × 18 cms. The choice among the better class of modern instruments is also not very easy on other grounds, for in spite of extraordinary optical perfection, in a certain position between the middle and the edge of the field of the picture, many produce a slight arching of the field, which is especially troublesome when we have a long focal length and a small plate. On this account instruments are to be preferred for balloon work (when they are used under a small angular aperture) which are corrected for an angular aperture not too large; and having regard to the measuring out of the plate afterwards, only such instruments should be chosen as are perfectly free from errors of this type, *i.e.* are symmetrically anastigmatic. The following instruments may be recommended as very symmetrical:—Görz's Double Anastigmat, Ser. III.; Voigtländer's Collinear, Ser. III.; Zeiss's 'Satzprotar,' Ser. VII. *a.*

By using very sensitive dry plates the velocity of the shutter may be extraordinarily great, under favourable circumstances, assuming that the objective chosen is used with the full opening. With downward exposures on a clear day, when there are no intensely illuminated clouds under the car, an exposure of about $\frac{1}{300}$ sec. will give a correctly illuminated photograph. In dull weather $\frac{1}{150}$ to $\frac{1}{200}$ sec. is sufficient. For exposures of clouds strongly illuminated, especially cumulus and other brightly lighted pictures, for which, as we shall see later, it is best to use colour-sensitive plates, the time of exposure may be further considerably reduced, and the objective aperture may also be greatly diminished. If we consider that, in photographing clouds from the ground, through the thick strata of the lower atmosphere, which absorb much of the active light, we require generally but a $\frac{1}{50}$ sec. exposure, with an opening of *f*/40, we

can at once see that on board the car a very much shorter exposure or a greatly decreased aperture will be required.

The conditions are quite altered if, instead of an ordinary plate, we use a colour-sensitive or isochromatic plate in combination with a yellow screen. It may be stated here that the use of isochromatic plates is to be recommended in every case, since even on the clearest day the fine blue mist lying over the surface of the earth causes the details of the surface to come out badly on an ordinary plate, just as though they had been observed through a veil. It is still less possible to obtain the finest details of a cloud picture, *e.g.* of cirrus clouds, which are depicted against the blue sky, on an ordinary plate. The contrasts will not come out sufficiently strongly even with the shortest exposure; indeed, cirrus clouds, as we know from experience, are usually missing altogether on the plate. The conditions are quite different when we use the isochromatic plates. The action of the colour-sensitive plate is to cause the less refrangible rays, especially the yellow and yellowish-green rays, to come out more strongly as compared to the blue rays, in the photographic action, than on ordinary plates. Light passing through a mist affects the plate, and causes the layers between the place of exposure and the object to appear more transparent and lighter, whence all details come out most distinctly. These show clearly with the use of isochromatic plates with or without a yellow screen. The yellow screen is of the greatest advantage in all cloud photography, especially in photographing cirrus clouds. It is best to use the yellow screen near to the objective, and for this purpose bright yellow glass whose sides are optically plane and parallel should be employed; this may be procured of good quality from several different firms. Still better than these glasses are liquid cells between plane parallel plates; these cells are filled with a sufficiently diluted solution of potassium bichromate.

The best colour filter which can be used for balloon exposures consists of two perfectly plane pieces of glass cemented together, and enclosing between them a coloured layer, this being comparatively strong and extremely transparent. These glasses not only absorb almost perfectly the strongly refrangible light, but they are almost perfectly transparent to the less refrangible light which we wish to act on the plate, while coloured glass always absorbs part of this, on account of its impure colouring. With the aid of such colour filters instantaneous photographs are easily taken from the balloon, using, of course, isochromatic plates.

The use of isochromatic plates in combination with a yellow screen represents the greatest advance which has been made in balloon photography; instead of only using a small fraction of

the light reaching the objective, with this arrangement the full aperture is used, and by absorbing all the blue light by means of a suitable yellow screen all details in the distant objects come out much more strongly without further trouble.

The kind of colour plate to use depends principally on the kind which the particular photographer has been accustomed to and has had experience of. In general, good colour plates are manufactured in commerce, but it must be remembered that such colour-sensitive plates are usually not very durable, and care must be taken to choose them as fresh as possible. Old isochromatic plates often give dull edges and irregular spots. Perutz's Erythrosin Silver Plate may be recommended as a good plate with considerable colour action. It has recently been produced as a highly sensitive plate, with which an instantaneous exposure may be safely made even when the yellow screen is used.

Those who wish to attain the best possible results must, however, prepare their own plates, and the following recipe gives an exceedingly sensitive plate very suitable for balloon work, as careful tests have shown, and, even when used in combination with a powerful yellow filter (the filter of the Photochemical Laboratory of Berlin, by R. Talbot, Berlin), can be used for instantaneous work, even though the light may be somewhat unfavourable. The plates which are to be made isochromatic must offer a clear working and very sensitive emulsion. For the purpose of sensitising they are dipped in a weak ammonia bath (1–2 per cent) in the dark room with a dark red light, and after two minutes are transferred without rinsing into the Erythrosin solution—1–500 erythrosin solution, 15 c.c. ; water, 100 c.c. ; ammonia, 1 c.c. The plates must remain in this bath for two minutes, being kept in motion all the time, and then taken out and washed well for two minutes under a rose. After this they must be placed in a good drying cupboard where they stand on a rack, and should be dry in from three to four hours. The plates prepared in this manner may be preserved for use at any time, since they remain unaltered for at least three to four months. The sensitiveness of these plates is very much greater than that of the mother emulsion, and they can be employed with advantage even without the yellow screen, and will give in a good light an instantaneous photograph with an objective aperture of $f/24$ and a time of exposure of $\frac{1}{50}$ sec.

The use of such super-sensitive colour plates is especially to be recommended when teleological exposures are to be made from the balloon. The ordinary tele-objective (Voigtländer, Steinheil) allows instantaneous exposures to be made from the balloon by means of such plates, when the enlargement is not too great (three to four times the original focal length of the

positive system), and a picture may be obtained in this manner with a camera drawing out only 25–30 cms., such as could only be obtained with an ordinary objective by means of a camera 75–100 cms. long. In this way instantaneous photographs for detailed study of the land below can be obtained by exposures in the balloon.

§ 5. CHEMISTRY.

The chemical manipulations which are necessary for the development of the balloon photograph do not differ essentially from those which have to be carried out with ordinary plates, but it is advisable to carry out the development of such valuable photographs, of which each may be a unique specimen, with special care. On the ground of a very long experience we can recommend the so-called rodinol developer, amongst the large number in use, as being especially suitable for the development of valuable photographs taken perhaps with an exceedingly rapid exposure. For our purpose it may be used with advantage in the form of the so-called permanent developer. The stationary development is a form of development in which. by handling the plates in a very dilute solution of the developer, and so requiring a very slow development, we seek to bring out the greatest amount of detail, the finest possible granulation of the layer, and the equalisation of any faults of exposure. The method which can be recommended most strongly is the following:—

The plates are removed from the holder either in the feeblest red light or in the dark and carefully dusted (the same process must be gone through when inserting the plates, and the camera and holder must be kept absolutely free from any trace of dust), and placed side by side in a developing stand in which a dozen or more plates may be treated. The developing vessel should be a glass or glazed earthenware trough, of such dimensions that there is ample room for the developing stand, and so that the upper edge of the plates comes at least 5 cms. below the upper edge of the vessel. The trough should be filled to within about 2 cms. of its upper edge with distilled water to which 1 c.c. rodinol solution is added for every 250 c.c. water. After the plates have been put into the very weak developing solution, the sensitive side must be gone over with a fine camel's hair brush, in order to remove all air bubbles adhering to it, the trough being afterwards covered with a piece of cardboard. The development progresses extremely slowly, so that it is hardly necessary to see how it is going on before the expiration of an hour. As soon as it is seen that the details of the plate stand out well, even in the deepest shadow, the slow development is

interrupted, and we proceed to bring out the necessary contrasts in the plate by developing further in a concentrated developer.

One plate after another is taken out, examined, and brought eventually, if the contrasts are not sufficiently strong, into a 1 to 20 rodinol solution, in an ordinary developing dish. The plates are developed in this until the contrasts are properly brought out. Usually, when everything has been properly carried out, this second development is unnecessary. The plates acquire, on the contrary, a sufficient density after standing about 2–2½ hours in the weak solution, and show beautiful rich contrasts, though full of detail, even in the shadow portions. If the illumination was too powerful, so that the plate appears misty, even in the diluted developing solution, and covered with a uniform grey layer at the time of inspection, it is treated further in a concentrated developer 1 to 25, to which has been added 10 to 15 c.c. of a 10 per cent. solution of potassium bromide for every 100 c.c. of the developing solution. The plate has been under-exposed if it has to stand five or ten hours in the dilute developing solution before showing any detail, the lights coming out very strongly. Nothing can be done with these plates, which, however, are seldom obtained in balloon work. In this class of work, in fact, even with the shortest exposure, we have almost always to deal with cases of over-exposure.

§ 6. FINISHING TOUCHES.

The methods of treating the plates further in case they are too faint, *i.e.* if the contrasts are too feeble, or in case they are too strong, *i.e.* the contrasts are too great, in order to correct these faults, and the methods of obtaining positives (prints) are the same for balloon photographs as in ordinary work. These particulars, as well as the principles of photographic knowledge, may be obtained from any small text-book on amateur photography. Pizzighelli's *Anleitung zum Photographieren* may be recommended as a work for beginners, and as one in which most of the questions and doubts, puzzling to the beginner, are answered. In any case, it is better to take up balloon photography only when thoroughly expert in ordinary photography, and after a certain mechanical routine has been attained, without which neither ordinary exposures, and still less balloon exposures, can be made to yield results of value, at least with certainty.

CHAPTER VIII.

PHOTOGRAPHIC SURVEYING FROM BALLOONS.

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§ 1. GENERAL CONSIDERATIONS.

THE application of photographic surveying during balloon voyages serves a double purpose, viz.:—

1. The determination of the position of the balloon with respect to a number of terrestrial points, whose position and altitude is already known, and which can be identified on the photograph.

The vertical projection of the position of the balloon can then also be shown on the map, and the altitude of the balloon determined.

2. For the construction of a map of the ground on the basis of a knowledge of several points which have been identified. If one photograph only is used, the construction can only be carried out on the assumption that the land is plane. Using, however, two or more photographs taken from different positions of the balloon, we can free the map from this restriction, and determine also the vertical aspect of the land.

The following conditions must be fulfilled by the apparatus:—

(1) The objective must give an exact perspective image (test by photographing two parallel lines, say plumb lines).

(2) The position of the emulsion relatively to the objective must remain the same after the introduction of the plate. This is best attained by fastening the base plate to the objective as firmly as possible, and by pressing the holder and plate firmly against a fixed edge by means of springs. The emulsion should stand out nowhere above 2 mm. from the fixed edge. It is as well to attach one or two spirit levels to ensure that the frame is vertical.

The plumb-line falling on the plate from the centre of perspective of the apparatus (the second principal focus of the objective) should meet the plate nearly in the middle of the illuminated surface; this is fulfilled in some degree with an ordinary apparatus. The position of the point of intersection—the "principal point" of the photograph, and its distance from the centre of perspective—the "picture distance"—are determined once for all before using the apparatus; a repetition of this determination is only necessary when an alteration in the relative positions of the objective and plate is liable to have occurred from any cause. Small deviations in the position of the plate with respect to the holder can be accounted for by corrections of the "picture distance" and the "principal point." The corrections are easily found by comparing the actual dimensions of the frame (which should be chosen as an exact rectangle) with the dimensions of the picture on the plate.

If the plate is reversed (sensitive side behind) in the apparatus, the construction can still be fairly accurately carried out, if we increase the "picture distance" by the thickness of the plate, divided by the index of refraction of the glass.

The field included in the photograph should be large enough to enable several points on the photograph to be identified.

Measurements on the negative are more exhausting to the eyes, but more exact than those on the positive; in the latter case it must be noted that in the process of drying the positive, the paper contracts, and may contract a different amount in different directions. This must be allowed for by comparing the size of the negative picture with that of the positive, the measurements being suitably reduced. In using enlargements we must note that the rectangular picture on the negative may be no longer rectangular after enlargement.

The construction may be greatly simplified by furnishing the balloon with sixteen to twenty strings hung at equal distance around the equator—plumb lines—each being about 50 metres long, 3 mm. in diameter, and stretched by small bags holding pieces of lead weighing about 100 gm. each.

§ 2. DETERMINATIONS OF THE CONSTANTS OF THE APPARATUS.

Imagine rays drawn from the point at which the photograph is taken (or more exactly from the first principal focus of the objective) to the objects depicted, then the photographic picture fits into this bundle of rays so that the points of the picture lie on the rays towards the corresponding points of the

object. If the coincidence is perfect, then the centre of the rays lies exactly in the position of the centre of perspective sought for, relatively to the picture. The perpendicular distance of the focus from the picture is the desired "picture distance," and the foot of the same on the picture the desired principal point of the photograph.

The geometrical starting-point of photographic surveying is, as is clear from the foregoing, that the angle subtended by two points P_1 and P_2 at the point of exposure can be found by the aid of the picture. In this sense the photographic surveying apparatus replaces the theodolite, while it has considerable advantages over the latter for measurements from balloons (on account of the continuous alteration in the position of the balloon), since all the data for calculation are furnished in one and the same moment. The desired angle under which P_1 and P_2 are seen at the point of exposure is identical with the angle subtended by the corresponding points p_1 and p_2 of the picture at the centre of perspective C. If the "picture distance" d and the principal point O on the illuminated surface are known, then the angle may be calculated in the following manner:—

With O as origin, form a rectangular co-ordinate system $x\,y$ on the picture (parallel to the edges of the picture), and measure the co-ordinates $(x_1\,y_1)$ and $(x_2\,y_2)$ (exactly to within 0·1 mm.) of the points $p_1\,p_2$ of the picture. Then the distances Cp_1 and Cp_2 are respectively equal to $\sqrt{d^2+x_1{}^2+y_1{}^2}$ and $\sqrt{d^2+x_2{}^2+y_2{}^2}$, and the distance $p_1\,p_2$ equal to $\sqrt{(x_2-x_1)^2+(y_2-y_1)^2}$. The desired angle may be found from the triangle $p_1\,Cp_2$, using the cosine relation, since all the sides of the triangle are known. The angle may, however, be more conveniently found graphically. We set $OC=d$ (fig. 64), and at right angles to this the distances measured on the negative $Op_1{}^1=Op_1$ and $Op_2{}^1=Op_2$; $Cp_1=Cp_1{}^1$ and $Cp_2=Cp_2{}^1$ appear then of the lengths shown in the figure, and from these and the length $p_1\,p_2$, found from the negative, the desired triangle and angle may be graphically determined.

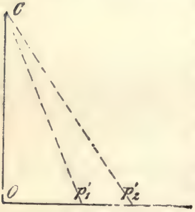

FIG. 64.

On the other hand these considerations serve also for the determination of the constants of the apparatus. The angle between two objects, situated at a distance apart of at least 100

metres, is determined by means of a theodolite, and an exposure is made at the same place (with the first nodal point of the objective at the point occupied by the axis of the theodolite), then the value for the angle determined photographically must give the same value. If this is not the case the "picture distance" and the position of the principal point must be corrected until identical values are obtained. The comparison of three proximate angles photographically determined is theoretically sufficient to determine the constants, but practically five or six angles are compared, which are as large as possible, and spread over the whole surface of the picture.

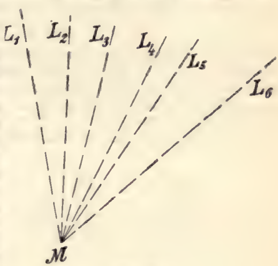

FIG. 65.

It is best to choose as objects vertical lines L_1 L_2 . . . . approximately in the horizontal plane of the point of exposure, such lines as corners of houses or chimneys, lightning conductors, etc., being chosen, and to bring the plate, by setting the screen, in as vertical a position as possible for the exposure. Now draw in the horizontal angles as measured with the theodolite on transparent paper; they give a bundle of rays ML_1 . . . . (fig. 65), and draw on the other hand the distances between the parallel lines l_1 l_2 . . . . (the images of L_1 L_2, etc.) on the picture, on a piece of drawing paper in a straight line (figs. 66 and 67).

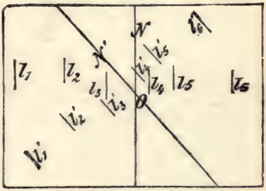

FIG. 66.

Now lay the transparent paper over the drawing paper so that any ray ML goes through the corresponding point l on the straight line (fig. 68). If we now draw the perpendicular MN, its length is the "picture distance," which may be found very accurately in this manner). The principal point lies on the line through N (on the picture) parallel to l_1 l_2. . . . If the apparatus is now turned by a

rotation about an axis perpendicular to the plate, so that the plate still remains vertical in its new position, and a second exposure is made of the lines, then the picture on the plate is

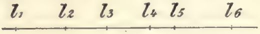

FIG. 67.

the same as before, only turned through the same angle as that through which the apparatus has been turned. In this way a new determination of the "picture distance" may be obtained, serving as a control of the previous one, and another straight line N′ (parallel to $l'_1\ l'_2$ . . . .) on which the principal point also lies, whence its position is determined (at O) (fig. 66). In

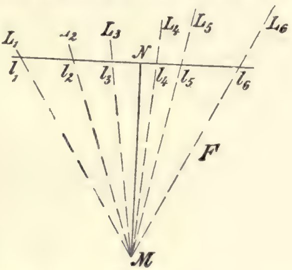

FIG. 68.

general, all these constructions give the "picture distance" with greater exactness than the position of the principal point; on the other hand, an error in the former is of greater importance in applications than a similar error in the latter.

For a first approximation, the "picture distance" may be taken as the focal length of the objective, and the principal point as the middle point of the illuminated rectangle.

§ 3. DETERMINATION OF THE POSITION OF THE BALLOON.

Method 1.—The plumb lines are taken as the vertical lines. On the photograph they are depicted as straight lines all meeting in a point q (fig. 69). The ray through the centre of perspective C and q is the vertical through the position of the

balloon, the point Q on the land, corresponding to q, is in the vertical projection of the balloon. If it is possible to identify q with Q on a map of the land photographed, then the projection is hereby determined. It is, however, not necessary, in order to find Q, to identify the point directly; q may, for example, lie completely outside the photograph. It is simplest to determine Q graphically in this case, if we can identify any two points of the picture, on two rays drawn through Q, say p_1 and p_2 as well as p_3 and p_4 with the points P_1, P_2, P_3, and P_4 on the map. Then Q is the point of intersection of $P_1\ P_2$ and $P_3\ P_4$. If we cannot identify any such points, we may proceed as follows:—

Join q with the principal point O, on the photograph, and draw through O a system of co-ordinates whose axes are Oq and the perpendicular to it (fig. 69). Now measure out the co-ordinates of the points on the photograph already identified $p_1\ p_2$ . . . . with respect to this system, and let them be $(x_1\ y_1)$ $(x_2\ y_2)$. . . .). Draw now the elevation with respect to the vertical plane COq (C being the centre of perspective). Since CO is equal to the "picture distance," and Oq is known by measurements on the photograph, the ray CO′ may be at once drawn in the elevation. The points $p_1\ p_2$ . . . . appear as the points $p'_1\ p'_2$ . . . . at distances $y_1\ y_2$ . . . . from O along O′q' (fig. 70). From the elevation thus drawn the plan may be easily obtained, remembering that the distances of the plans of $p_1\ p_2$ . . . . from the straight line O″q'', the projection of Oq in the plan (the corner of plan and elevation), are simply $x_1\ x_2$. . . . The plan of the bundle of rays is hence found: lines are drawn with q as centre to $p_1\ p_2$ . . . and these are identical with the lines drawn on the map from Q to $P_1\ P_2$. . . . If one fits the bundle of rays $q''\ p_1''\ p_2''$ . . . . in the map so that $P_1\ P_2$ . . . . lie exactly on the corresponding rays, then the centre of the bundle coincides exactly with the position of the desired point Q on the map (fig. 71).

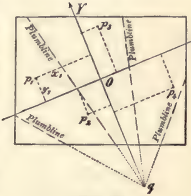

FIG. 69.

This construction will be very exact if the number of points p and P identified with one another is not too small; it holds also for uneven land.

The altitude of the balloon may be determined by constructing the angle p_1Cq by the method described in § 2; let it be α, and the distance P_1 Q measured on the map be l. Then l cot α is the difference in altitude of the balloon and the point P_1

above sea level, and the height of the balloon above sea level is known if we can obtain that of P_1 from the map, either directly or by interpolation.

The following construction may be used to determine the height if Q is determined by the second method :—

Suppose the map is laid horizontally through P_1 and that the perpendicular $p_1 r_1$ on to Cq is drawn. Then the triangles $P_1 QC$ and $p_1 r_1 C$ are similar, and the height of the balloon above P_1 is

$$QC = \frac{P_1Q \cdot r_1C}{p_1r_1};$$

$P_1 Q$ may be taken from the map, $r_1 C = p_1' r_1'$ and $p_1 r_1 = p_1'' q''$ on the elevation and plan respectively, hence the height of the balloon may be calculated.

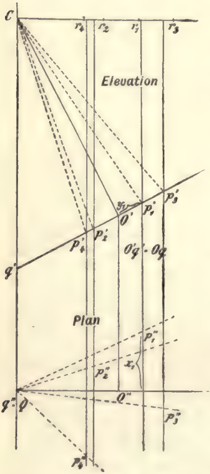

FIG. 70.

The rare case, that only one plumb line falls on the photograph, thus not giving the position of q, is more difficult to handle.

In this simple method, requiring but little time to compute the position of the balloon, we make the assumption that the plumb lines are also vertical lines. The errors introduced by this assumption, which may be due to the fact that the exposure is made at a moment when the horizontal velocity of the balloon is rapidly altering, are small, but investigations on this point are worthy of consideration.

Method 2. — The following method is free from these assumptions. Let p_1, p_2, p_3 be three points on the photograph which have been identified with the points P_1, P_2, P_3 on the chart. If it is possible to identify more than three points, then three are chosen so as to enclose the largest possible triangle $p_1 p_2 p_3$. Since the angles $p_1 Cp_2$, $p_2 Cp_3$, $p_3 Cp_1$ may be constructed as in § 2, the three angles at the apex of the pyramid, whose apex is the position of the balloon and whose base is the triangle $P_1 P_2 P_3$

on the land made by the three sides (the plane angles), are known. Furthermore, the distances $P_1 P_2$, $P_2 P_3$, $P_3 P_1$ on level ground are easily found from the map, the differences of height being taken into account if considerable. From these data the pyramid may be calculated out. It is, however, much easier to proceed graphically. This is done in the following manner :—

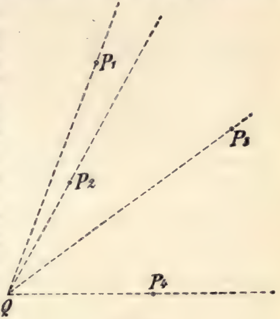

FIG. 71.

Lay out the three angles subtended at the balloon in a plane, where α, β, γ are the angles p_1Cp_2, p_2Cp_3, p_3Cp_1 respectively (fig. 72). Then take any point P'_1 on CP_1 and obtain the position of P'_2 by finding the intersection of the circle drawn through P'_1, of radius $P_1 P_2$ (a known distance) with the line CP_2. In a similar manner we can get P'_3 and P'_4, where $P'_2 P'_3$

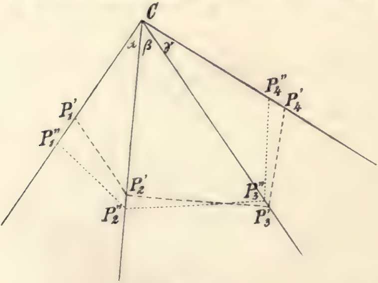

FIG. 72.

and $P'_3 P'_4$ are respectively equal to the known lengths $P_2 P_3$ and $P_3 P_1$. If the length CP'_4 happens to be equal to the length

CP_1, the first part of the problem is solved. The pyramid, developed as shown, could be put together in such a way that CP'_1 and CP'_4 would coincide with one another, and the desired pyramid would have been obtained on the scale of the chart. If CP'_4, however, is not equal to CP'_1, another point P_1'' must be chosen, and the construction repeated until we succeed in making $CP''_4 = CP''_1$. After some little practice success will usually be attained after the third or fourth attempt, since the first trial will show if P'_1 must be taken further away from or nearer to C. If great accuracy is required, then after a good approximate value for CP_1 has been found by the graphical method as described, the corrections which must be made to CP, in order to determine the length of the edge of the pyramid with perfect accuracy, may be determined by calculation with logarithmic differences.

The problem treated has four solutions, of which two may be imaginary and one to three negative, and therefore capable only of giving worthless values. Even if several possible solutions exist there can seldom be any doubt as to which is the correct one to take, as the mere comparison of the photograph and chart gives enough confirmatory points; if, however, a doubt still exists, a fourth point p_4 which can be identified with a point P_4 on the chart must be taken in order to decide the question.

The next step is to determine the length and the position of the foot of the perpendicular drawn from C, as the position of the balloon, on to the base of the pyramid $P_1 P_2 P_3$. If the three points P_1, P_2, P_3 are at the same height above sea level, this gives at once the perpendicular height of the balloon above P_1, while the foot of the perpendicular is the vertical projection of the position of the balloon on the earth. If P_1, P_2, P_3 lie at different heights above sea level, a correction must be applied to the balloon co-ordinate so obtained.

The position of the foot of the plumb line in the plane $P_1 P_2 P_3$ may be obtained thus:—Develop the pyramid $C P_1 P_2 P_3$ in a plane again (fig. 73) and draw $\bar{P}_1$ so that $P_2 \bar{P}_1 = P_2 P_1$ and $P_3 \bar{P}_1 = P_3 P_1$, and the triangle $\bar{P}_1 P_2 P_3$ is congruent with the base triangle $P_1 P_2 P_3$. Draw the perpendiculars $C R_1$, $C R_2$, $C R_3$ and make $P_3 R_2 = P_3 S_2$, $P_2 R_3 = P_2 S_3$. The perpendiculars through S_2 and S_3 and the perpendicular $C R_1$ cut in a point Q (which gives a partial control of the accuracy of the drawing), and Q gives the foot of the desired perpendicular from the balloon on to the plane $P_1 P_2 P_3$ in its relative position to the triangle $\bar{P}_1 P_2 P_3$. If $P_1 P_2 P_3$ lie at the same height, then the figure may be laid at once on the map, so that $\bar{P}_1$, P_2, and P_3 cover the points known as P_1 P_2 and P_3 on the map. Then Q lies exactly over the vertical projection of the balloon on the map.

The length of the perpendicular from the balloon on to $P_1 P_2 P_3$ is $L = \sqrt{(CR_1)^2 - (QR_1)^2}$, which may be easily found graphically. This is, in the special case already mentioned, equal to the height of the balloon above the horizontal plane $P_1 P_2 P_3$.

Let us take now the general case and let the difference in altitudes of P_2 and P_1 be δ_2, measured on the scale of the chart,

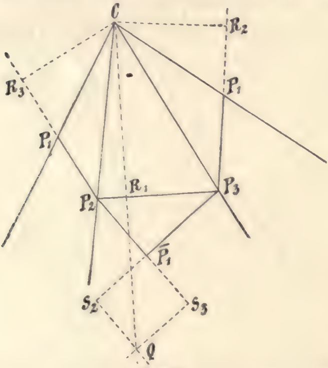

FIG. 73.

and the difference in height of P_3 and P_1 be δ_3. Let the length $P_1 P_3$ (fig. 74) be divided by a point T, so that

$$P_1 T : P_1 P_3 = \delta_2 : \delta_3.$$

Through P_1 draw a parallel $P_1 W$ to $P_2 T$ and drop the perpendiculars $P_1 V$ and QU. The problem is to bring the pyramid $CP_1 P_2 P_3$ by a rotation about the axis $P_1 W$ from a position in which $P_1 P_2 P_3$ is a horizontal plane, into a position corresponding to the actual differences of level δ_2 and δ_3. The position of the apex of the pyramid C after the rotation gives the position of the balloon.

The angle ϕ, to be turned through, is given by $\sin \phi = \frac{\delta_2}{P_1 V}$.

The co-ordinates of C before the rotation, with respect to O as origin, $P_1 W$ and $P_1 V$, and the line mutually perpendicular to them as axes, are: UP_1, QU, and $CQ = L$.

After the rotation the co-ordinates of C with respect to P_1 as origin, P_1 W, the projection of P_1 V on to the horizontal plate (*i.e.* P_1 V after rotation) and the vertical are
U P_1 (unchanged) ; $QU \cos\phi + CQ \sin\phi$; $CQ \cos\phi - QU \sin\phi$.

With these the position of the balloon may be determined. The correction in the height as against the assumption that P_1 P_2 P_3 lie in a horizontal plane, when the height of the balloon was equal to the height of the pyramid $CQ = L$, is

$$-L(1-\cos\phi) - QU\sin\phi = -L2\sin^2\frac{\phi}{2} - QU\sin\phi.$$

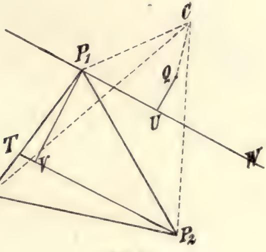

FIG. 74.

Even with a small angle ϕ, *i.e.* a not very uneven surface, this correction may be important if Q U is large, *i.e.* if the rays to the points identified cut the horizontal plane at a very acute angle.

This second method of determining the position of the balloon has the advantage of mathematical exactness, but the disadvantage of being very tedious in its application.

§ 4. CONSTRUCTION OF A PLAN.

The following general law holds always, if a picture of an object is obtained by one or more perspective projections :—

If four points of the object P_1, P_2, P_3, P_4 lie on a straight line, then the corresponding points p_1, p_2, p_3, p_4 of the image (picture) also lie on a straight line, and in such a manner that the quotient of $\frac{P_1P_3}{P_2P_3}$ and $\frac{P_1P_4}{P_2P_4}$ (the "double relation" of the points P_1, P_2,

P_3, P_4) is equal to the quotient $\frac{p_1p_3}{p_2p_3} : \frac{p_1p_4}{p_2p_4}$ (the "double relation" of the points p_1, p_2, p_3, p_4).

By this law P_4 can be found if P_1, P_2, P_3 and p_1, p_2, p_3, p_4 are given. Graphically we can proceed thus: the lines $P_1 P_2$ and $p_1 p_2$ are laid so that P_1 coincides with p_1. If $P_2 p_2$ and $P_3 p_3$ intersect in Z, then Zp_4 intersects the line $P_1 P_2$ in the desired point P_4 (fig. 75).

If the land is plane, as is here assumed, the map and photograph are perspective projections of one another. If, then, four points A, B, C, D and *a*, *b*, *c*, *d* have been identified on the two, then we can find any point E on the map which corresponds to a point *e* on the negative. Join *f*, the point of intersection of *a b* and *c d*, to *e*, and let *h* be the point of intersection of *f e*

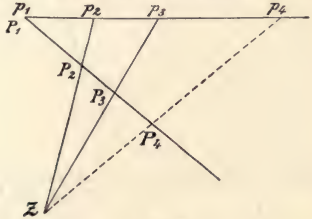

FIG. 75.

with *b c*, then we only require to construct the point H on the map so that the double relation of G C B H is equal to that of *g c b h*. Then F H on the chart corresponds to *f h* on the negative, and E lies on the line F H A second line determining E may be found in an exactly analogous manner, G J being this line, whence E is determined (figs. 76*a* and 76*b*).

If it is desired to mark a large number of points on the picture in the plan, *i.e.* to draw the plan itself (with the exception of a few points already determined), we can use another construction—Möbius's net—instead of that described above.

In the foregoing figures, points lying within the quadrilateral *a b c d* of the photograph correspond to those lying within A B C D on the chart. Similarly the points inside the smaller quadrilateral *a j e l* correspond to those inside A J E L. By continuing such divisions of quadrilaterals we can always relate smaller quadrilaterals on the picture and chart to one another,

leading finally to the production of sketch map. The division into smaller regions is most conveniently accomplished by

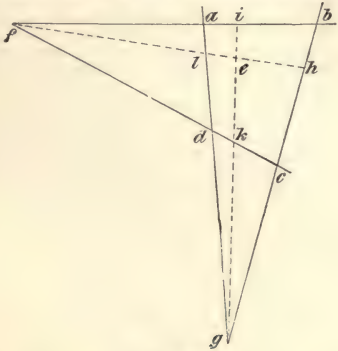

FIG. 76 *a*.

drawing diagonals one after another. Suppose the diagonals A C and D H intersect at E (fig. 77), the quadrilateral is hereby divided into four smaller triangles. By joining E F and E G a further division is made. The diagonals J H, H K, K L, L J continue this further, the connection of the points of intersection of E B and J H, etc., with F and G gives new divisions, and so we progress forward without further difficulty. A point in any one of the triangles on the photograph must be drawn in as a point in the corresponding triangle on the map; with a little practice the positions inside the triangles may be correctly judged and

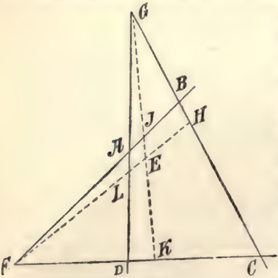

FIG. 76 *b*.

transferred, thus saving the necessity of the mesh system being carried to too fine a limit. It is further obvious that the division into these small regions can be carried out outside the quadrilateral; the prolongations of J L and J H cutting the line F C in points, whose juncture with G will further the division of the region outside the quadrilateral. Important controls of the drawing may be obtained by noting that a row of rays (*e.g.* K H, D B, L J) cut F G in one point, and by many similar theorems.

The formation of the map will often be rendered easier by the remark that, if a straight line (or curve) touches a curve in the photograph (as, for instance, a street and the edge of a wood), the

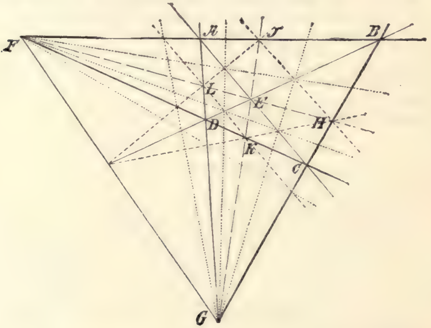

FIG. 77.

same holds true on the map, and naturally at corresponding points.

If the unevenness of the land is to be taken into account, at least two photographs are necessary for the reconstruction. The problem is then somewhat more difficult, and we can only just indicate the solution here. In the first place the position of the balloon must be found, as in § 3, for both cases. Let P_1, P_2, P_3 be the three points identified in the first photograph. Then imagine a horizontal plane laid (more conveniently through one of the points), and find the intersection of this plane with the rays from the balloon C to P_1, P_2, P_3, and let these points of intersection be P'_1, P'_2, P'_3.

Möbius's net construction may now be applied in the

horizontal plane; it gives the point R for a point in the photograph. Now repeat the same process for the second photograph, keeping to the same horizontal plane. If the point r' of the second photograph is known to be identical with the point r of the first, and if R′ is the point corresponding to r' in the horizontal plane, then R and R′ will not in general coincide. If they happen to fall together, then the true point on the earth, projected from C and C′ to R and R′ of the horizontal plane, coincides with them both, and lies in the point R (R′) in the horizontal plane. In the general case the point on the land must be graphically constructed or calculated as the point of intersection of the lines C R and C′ R′.

The fact that these lines cut one another actually in space gives an excellent control of the whole foregoing construction.

The construction of a map from balloon photographs, in addition to its especial use in war, may be advantageously employed to survey flat unapproachable land (such as marsh land). The views obtained from a balloon, especially taken from a captive balloon where the height is not very great, are frequently insufficient for the survey of very hilly land.

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CHAPTER IX.

ON MILITARY BALLOONING.

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A.—DEVELOPMENT AND ORGANISATION.

§ 1. GERMANY.

1870. 31 Aug. Formation of two balloon detachments in Cologne, each of strength, 1 officer and 20 men (Lieut. Joesten, Lieut. d. R. Mieck). Purchase of two balloons (1150 cb. m. and 650 cb. m.) from the English aeronaut Coxwell.

10 Sept. Arrival of the detachments in front of Strassburg.

24 Sept. Ascent outside Strassburg.

10 Oct. Detachments disbanded outside Paris (*cf. Z. f. L.*, 1883. Frh. v. Hagen, *Geschichte der Militär-Aëronautik*).

1872. Experiments made by the Garde-Pioneer Battalion in Berlin (Capt. Fleck); preparation of hydrogen by the wet method. Small captive balloon built (*cf. Mitteilungen des Ingenieur-Comités*, vol. xviii., 1873).

1884. June. Experimental station for captive balloons equipped by the Minister for War at the request of the Fussartillerie-Schiesschule, 4 officers (Capt. Buchholtz, Lieut. von Tschudi, Lieut. Frhr. von Hagen, Lieut. Moedebeck), aeronaut Opitz, 4 non-coms., 29 rank and file. Barracks and workshops at the Ostbahnhof in Berlin (*cf. I. A. M*, 1900, p. 106).

Captive balloons built ("Angra-Pequẽna," 112 cb. m.; "Barbara," 1400 cb. m.; "Cigarre" and "Danaë"). These were experimented with.

1885. Continuation of experiments. Participation in the shooting courses of the Artillerie-Schiesschule and in an artillery siege practice near Cologne. Officers instructed

in working free balloons. Balloons built ("Electra," "Fatinitza," "Galathea," "Haparanda").

1886. Mar. Augmentation of staff to 1 major, 1 captain, 2 lieutenants, 1 assistant paymaster, 1 orderly, 34 non-coms. and men.

The detachment received an exercise ground on the Tempelhofer-Feld. Formation of field balloon stores: steam winch, C/86 with 600 metres of steel cable; hydrogen generator, C/86; balloon waggon, C/86. Balloons built ("Iduna," "Komatzu," and "Lerche").

May. Augmentation of personnel to 1 major, 1 captain, 3 lieutenants, 1 aeronaut, 1 assistant paymaster, 1 orderly, 6 non-coms., 42 men. Designation, "Luftschiffer Abteilung" (Balloon Division). Attached to the railway regiment and placed under the General Staff. Captive balloons sent up by the Artillerie-Schiesschule. Free voyages. Improvement of stores.

1887. 1 Apr. Final formation of a Balloon Division; Garde-Pioneer uniform. Shoulder-straps marked "L"; rifles, 1871 pattern, as weapons. Frequent exercises with the Artillerie-Schiesschule.

Aug. Participation in the siege practice near Mayence.

1888. Introduction of the C/88 gas producer, Majert-Richter's system (*cf.* Chapter I., § 7), and the steam winch C/88. Experiments with compressed gas. Balloons built ("Möwe," "Nautilus").

1889. Participation in siege practice near Küstrin, and in the Imperial Manœuvres of the 10th Army Corps. Balloons built ("Orion," "Pegasus," "Quirinus").

1890. Lighter material used; introduction of the English system. Drill stores obtained for different fortresses. Exercises near Coblence, in the Eifel, on the training-ship *Mars* in Wilhelmshaven, and in several forts. Armed with '88 pattern rifles.

Formation of a Bavarian balloon school in Munich. Personnel: 3 officers (Capt. Brug, First Lieut. Kollmann, Lieut. Kiefer), 4 non-coms., 26 men. Attached to the Railway Battalion, and placed under the inspection of the Engineers.

1891. Exercises in Jüterbog, and in Heligoland.

1892. Participation in the manœuvres of the Garde-Korps (Capt. von Foerster).

The division took part in a combined movement on a war footing.

Armed with '91 pattern rifles.

1893. Exercises in Jüterbog; participation in the Imperial Manœuvres of the 16th Army Corps. Stores: balloon

1893. of 525 cb. m. (greatest height attained, 1800 m.); hand winch; hydrogen waggon with 20 cylinders, each holding 7 cb. m. of gas at 200 atm. pressure.

1 Oct. Augmentation of personnel to 1 major (Maj. Nieber), 1 captain, 4 lieutenants, 1 paymaster, 1 clerk, 1 senior and 1 junior warrant officer, 6 sergeants, 10 non-coms., 2 corporals, 14 lance-corporals, 1 assistant paymaster, 1 orderly, 104 rank and file.

1894. Equipment of a balloon school.

25 May Great explosion of gas cylinders, about 400 cylinders out of a total of 1000 exploding. (The *Nationalzeitung*, 25/5/'94; and the *Zeitschrift des Vereins deutscher Ingenieurs*, vol. xl., Nos. 26 and 27 of the 27/6/'96 and the 4/7/'96, give the fullest details concerning the investigation of the exploded cylinders.)

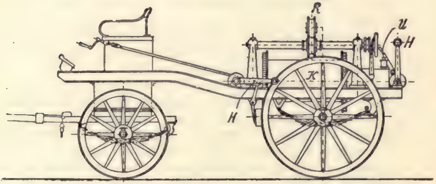


FIG. 78.—German winch-waggon for captive balloons (Krupp).

Experiments with a kite-balloon. Parseval-Sigsfeld's system.

Sept. Kite-balloon in use during the manœuvres of the 17th Army Corps in West Prussia (Capt. Pophal). Improvement in the field balloon stores.

1895. 14 Feb. Introduction of the "shako," after trial, for the Jägers, in place of helmets. Arms: '91 pattern rifles, and the infantry side-arms 71/84.

The Balloon Detachment was made an independent troop of the Railway Brigade. Official equipment of a balloon school; 10 officers per annum required to attend this. Personnel increased by two officers (Capt. Klussmann and First Lieut. Gross), who were to act as instructors.

1896. Introduction of the kite-balloon.

1898. New service regulations drawn up for the Balloon Detachment.

1901. 1 Oct. Formation of a Balloon Battalion of 2 companies and a Transport Division. Inspection of the new barracks in Reinickendorf West, near Berlin (*I. A. M.*, 1902, No. 2). Personnel : 1 staff officer (Major Klussmann), 2 chief instructors, 2 company commanders, 2 first lieutenants, 3 second lieutenants, 1 surgeon, 1 paymaster, 1 workshop foreman, 1 chief gunner, 2 senior and 2 junior warrant officers, 12 sergeants, 21 non-coms., 32 corporals, including 2 signallers, 227 rank and file, 3 labourers, 1 assistant paymaster, 2 non-coms. or lance-corporals, about 12 officers, 1 officer of the sanitary department, 3 clerks, 302 men. The Transport Division consisted of 1 first lieutenant, 1 second lieutenant, 1 sergeant, 4 non-coms., including 1 armourer, 1 trumpeter, 5 lance-corporals, 25 men in their second year of service, and 30 men in their first year of service (who were to be trained by the Training Battalion), 1 labourer, 14 riding horses, and 44 draught horses.

A mounted Field Balloon Division possessed 2 transport waggons, 12 gas waggons, 1 winch waggon, officers' horses, 2 store waggons, and a forage waggon.

Personnel: 1 division guide, 4 balloon lieutenants, 1 officer of the sanitary staff, 1 sergeant-major, 3 sergeants, 4 corporals, 12 lance-corporals, 87 men, 2 transport officers, 1 veterinary surgeon, 1 Wachtmeister, 1 sergeant, 4 non-coms., 9 transport men, 51 transport drivers, 1 assistant paymaster, 1 non-com. officer of the sanitary staff, 1 armourer (*cf. Ex.-Rglt. für Luftschiffer* of 17/10/'01 ; Berlin, 1901). The Balloon Battalion published a historic summary, on the occasion of the meeting of the International Congress for Scientific Balloon Expeditions—*Kgl. Preussische Luftschiffer Abteilung* ; Berlin, 1884–1901. In the roll of names in it were those of 215 German, 4 Bavarian, 6 Austrian, 1 Swedish, 1 Roumanian, and 1 Italian officer.

The number of free balloons used reached 29.

1902. 1 Feb. Death of Capt. Bartsch v. Sigsfeld at Zwyndrecht, due to a rough landing after a voyage in the balloon "Berson" with Dr Linke.

1904. Two Wireless-Telegraphy Divisions sent out to the seat of war in South-West Africa.

1905. Formation of a Wireless-Telegraphy Division in Berlin under Capt. v. Tschudi.

Two additional Wireless Telegraphy Divisions were sent to South-West Africa.

§ 2. AUSTRIA.

1849. Bombardment of Venice with balloon torpedoes, at the suggestion of Uchatius, an artillery officer, the range of the besieging batteries being insufficient to bombard the town.

Montgolfières, made of writing paper, were used. Cubical contents, 94 cb. m. They had at most a lifting power of 31 kg., and carried bombs weighing 15 kg. for 33 minutes.

Each balloon-torpedo battalion included :—

1 waggon with 100 Montgolfières.
2 waggons with about 50 fire buckets.
1 waggon with 60 projectiles.
1 waggon with 40 projectiles and a wind screen.

Method employed :—Station chosen on the windward side. Trial balloon liberated; course trigonometrically laid out on the chart. Balloon with bomb liberated after correctly timing the fuse. The station was changed from time to time according to the direction of the wind. Results—some bombs fell very favourably (*e.g.* one in the market-place) ; the moral influence was much greater than the actual damage done by the shells.

1866. Organisation of a Balloon Company for the garrison army of Vienna. 1 officer, 1 non-com., 60 men of the Inf.-Rgts. No. 27. Preparation of a balloon (1800 cb. m.) which escaped during the exercises (*I. A. M.*, 1901).

1888. Capt. Sandner, First Lieut. Hoernes, First Lieut. Schindler, and Engineer-in-Chief Dr Wächter sent to study military aeronautics in Berlin, Paris, and London.

1890. First military-aeronautical course in the aeronautical station by V. Silberer (14/4 to 5/8). 8 officers, 2 non-coms., 24 men. 48 free voyages and 14 captive ascents made.

1891. Second military-aeronautical course (1/5 to 17/8). 6 officers, 3 non-coms., 38 men. 54 free voyages made.

1892. Buildings erected (balloon shed, store-shops for a balloon division).

1893. Organisation of the Imperial Military Balloon Establishment (20th August). Personnel: 2 officers (Capt. Trieb and First Lieut. Hinterstoisser), 4 non-coms., 26 gunners; provided with German fort exercise stores. The establishment was placed under the First Regiment of Fort Artillery.

First course of instruction for 5 officers and about 60 men. 75 captive ascents, 15 free ascents.

1894. Personnel increased by 1 artilleryman, 4 corporals, and 36 gunners. Final course from 1st July to 30th October. Exercises by the general staff officers. 201 captive ascents, 20 free ascents. Practice in firing at balloons.

1894. Staff increased by 1 officer, 1 clerk, 6 men. Final course. 105 captive and 22 free ascents. Balloon Fort Division stationed in Pzemysel.

1896. Capt. F. Hinterstoisser appointed Commander of the Balloon Division. Continuation of the course in military ballooning. The Balloon Division took part in the manœuvres near Vienna and Buda-Pesth.

1898. The kite-balloon (600 cb. m.) was introduced for the field and fort Balloon Divisions. Personnel of the Military Balloon Institution fixed at 5 officers and 62 men. 20 officers and 320 non-coms. and men ordered to attend the military aeronautical course for 6 months in the year. During the course, 14 riding horses and 68 draught horses placed at the disposal of the Institute.

§ 3. SWITZERLAND.

As a result of a memorial by the federated General Staff of 10th October 1896, the formation of a Balloon Company as a part of the army was determined upon by law on 12th December 1897.

The personnel mentioned in the above law was raised, by resolution, on the 9th April 1901, and now consists of the following:—

Organisation of the Balloon Company in Berne: 1 company commandant, 2 first lieutenants, 2 lieutenants, 1 quarter-master, 1 train officer, 1 sergeant, 1 petty officer, 6 guards, 10 corporals, 1 train guard, 3 train corporals, 1 drummer, 1 train trumpeter, 2 shoe-smiths, 100 soldiers, 56 train lance-corporals and men. Total: 8 officers, 22 non-coms., 161 rank and file, 9 riding horses. And in vehicles: 1 cable waggon for a team of six, 1 baggage waggon, 1 tool waggon (for four horses), 14 four-horsed cylinder waggons, 6 single cylinder waggons, 1 travelling kitchen and smithy, 1 baggage waggon, 1 provision waggon. Total number of vehicles 28, requiring 91 draught horses.

Altogether 8 officers, 183 men, 100 horses, and 28 vehicles.

The exercises began in the summer of 1900.

§ 4. HOLLAND.

1886. Purchase of balloon materials in Paris. Concession of the same to the 6th Company of Engineers (Capt. E. Quarles van Ufford), which went through practices in Utrecht. The balloon "Kijkuit," made of cambric, had 900 cb. m. capacity; the hemp cable was 300 m. long. Hand winch used. (*Cf. Vereeniging ter Beoefening van de Krijgswetenschap*, 1886–87.)

The troops soon built the balloon "Telegraaf" (190 cb. m.) independently—used as a signalling balloon, as a gas sack, and as an experimental balloon. Only captive ascents were made. (For a description of the materials, see C. J. Snijder's *Handbook der Pionierkunst voor het nederlandsche Leger*. Schiedam, 1887.)

1890. 12–24 July. Experiments with a captive balloon in Weltevreden near Batavia (Major Haver Droeze and the aeronaut P. Spencer). Preparation of hydrogen in vats.

24 July. Embarkment for Atschin.

1 Aug. Arrival in Kota Radja. Arrangement of the station in Penditie. Inflation and ascents (8th August).

9 Aug. Transportation of the inflated balloon by train to Fort Lambaroe. Reconnoitring. In the course of transport by rail to Fort Lamreng (balloon fastened 30 m. high) the balloon was damaged by a tree. Since no new material for reinflating the balloon was available, the experiments were concluded. The repaired balloon was brought back to Batavia. (*Indisch militair Tijdschrift*, xxi., Nr. 7–12. Batavia, 1890.)

1902. An officer sent to the Military Aeronautical Institute in Vienna (First Lieut. Post van der Steyer). Organisation of a Balloon Troop. Balloon materials obtained from A. Riedinger in Germany and from Austria.

§ 5. BELGIUM.

1886. Balloon ordered for coal-gas filling (905 cb. m.), with hand winch, from Lachambre of Paris (*cf. L'A.*, 1888, p. 110). Transference of the same to Capt. Mahauden, Chef of the Compagnie des ouvriers du génie, in Antwerp (*cf. Revue militaire belge*, 1887, vol. ii.). There was much dissension caused on account of the balloon service being given into the charge of this company (*Z. f. L.*, 1890, p. 268).

1889. Formation of a balloon school. Chef du service

aerostatique, Capt. van den Borren. Experiments with Godard's hot-air balloons.

1891. Experiments with Bruce's signalling balloons (*cf. Z. f. L.*, 1891, and *Annual Reports of the Aeronautical Society of Great Britain*, 1893).

1893/94. Dirigible balloon built by the aeronaut Lieutenant Leclément de Saint Marcq, for the World's Fair at Antwerp. The project miscarried owing to insufficient preparation and experience. (For further details, see *American Engineer and Railroad Journal*, October 1894.)

§ 6. DENMARK.

1807–1811. Fruitless experiments with Kolding's air-ship (Frhr. v. Hagen, *Z. f. L.*, 1882, p. 354).

1886. Capt. Rambusch was sent to England, Belgium, and France to study aerial navigation. After his return a signalling balloon was built (13 ft. = 4 m. diameter, cable 150 m. long). Construction of a hydrogen generator, on Charles's system, by the Telegraph Company.

1889. Purchase of light balloon stores (balloon 350 cb. m., hand winch, gas generator) from Yon of Paris.

Oct. Commencement of practice with the stores. Transport on land and water.

1890. Observations on artillery shooting at 4000 ells = 2470 m.

1891. Observations on artillery shooting at 7000 ells = 4670 m. Annual exercises with the Telegraph Company in the years 1896, 1897, 1898. Free voyages were not undertaken. (*Luftballooner og. Luftsejlads of E. J. C. Rambusch, Ing. Kapt.* Copenhagen, 1893.)

A proposition, many years old, for the organisation of a Balloon Division, has not yet been carried out.

§ 7. SWEDEN.

1897. Balloon equipment ordered from Godard and Surcouf's.

Nov. Arrangement of an exercise place in the forts at Waxholm and Oscar Fredriksborg.

1898. 22 Apr. Capt. Jäderlund of the Fort Art. Rgt. 8, ordered to Versailles for 2 months to the 1 Rgt. du génie.

1900. 1 Aug. First Lieut. Amundson of the Génie Rgt. Nr. 1, ordered to Versailles for 3 months to the 1 Rgt. du génie.

1901. First Lieut. Saloman of the Fort Art. Rgt. 8, or-

1901. dered to the Austrian Military Aeronautical Institute in Vienna for 3 months.

The balloon stores comprised 1 silk balloon 540 cb. m., with all accessories, cable 500 m. long; a gasometer 60 cb. m.; 1 gas generator; 1 steam winch.

Personnel of the Balloon Detachment: 1 captain, 3 lieutenants, 2 non-coms., 2 corporals, 32 gunners.

1902. A kite-balloon and a spherical balloon of German make ordered from A. Riedinger. Building and testing of a special kite-balloon ship for the navy.

§ 8. ENGLAND.

1862. Experiments with captive balloons, to study their
14 July. use in military service, at Aldershot (aeronaut, Coxwell).

1871. Commission for aerial navigation called, consisting of Colonel Beaumont, Lieut. Grover, Engineer Abel. Erection of an arsenal at Woolwich. Experiments with coal-gas balloons.

1879. Decision of the Ministry to introduce military ballooning into the army. Formation of a balloon school at Chatham. Several balloons built (at first 4 for coal-gas, 14,000 to 38,000 cb. ft. = 390 to 1064 cb. m.; later, some for hydrogen, 6000 cb. ft. = 168 cb. m.). Invention of a light transportable gas-generating plant by Capt. Templer. Method: passing steam over glowing iron. Free voyages undertaken.

1880. Ministerial decree for the instruction of the 24th Company of Royal Engineers in ballooning. Part taken in all practices at Aldershot. Formation of a balloon factory and a Military School of Ballooning. Experiments on storing gas compressed in steel cylinders, and on the decarbonisation of coal-gas. Experiments on shooting balloons from 8″ Howitzers. The balloon stores consisted of 1 gas generator, 1 balloon waggon with hand winches, 1 store waggon (*cf. Z. f. L.*, 1883).

1881. Loss of the balloon "Saladin," with Mr Powell, in the
Dec. Channel.

1882. Balloon stores (3 officers and 3 balloons) sent to Egypt.
Sept. Arrived too late to take part in the military operations.

1884. Final formation of a balloon establishment at Chatham under Major Elsdale.

1885. Major Elsdale accompanied Sir C. Warren's expedition to Betschuana-Land (South Africa). Many ascents carried out. Balloon Detachment sent to the Soudan under Major Templer and Lieut. Mackenzie.

The stores were divided into two portions—transport

1885. division, consisting of 1 balloon waggon with hand winch, 1 store waggon, and 75 steel gas-cylinders carried by men. Each cylinder was 2·4 m. long, 0·136 m. in diameter, thickness of wall 5–6 mm., weight 36 kg., contents: about 3·6 cb. m. of gas at a pressure of 120 atmospheres, so that to fill a balloon of 196 cb. m. capacity required 60–70 cylinders. The second portion of the stores remained in the shipping harbour at Suakim, and comprised reserve materials including a large number of steel cylinders.

The hydrogen was prepared at Chatham, compressed and forwarded on from there. On account of the difficult transport conditions, the carriage of gas in gas sacks was soon abandoned.

Mar. April. Ascents during the marches towards Tamai. Discovery of Sinkat. The practical application of ballooning left nothing to be desired.

1886/87. Observation exercises on the artillery shooting grounds at Lydd. Shooting at balloons with 12-pounders.

1888. Composition of the ballooning stores: 1 balloon waggon with hand winch; balloons made from goldbeaters' skins of up to 360 cb. m. capacity; 760 m. steel cable; 1 store waggon; 4 gas waggons, each to hold 35 cylinders 2·7 m. long by 20 cm. diameter, in 5 rows (the simultaneous emptying of 3 gas waggons occupied 15 minutes; each cylinder contained 14 cb. m. gas at 120 atm. pressure). 3 riding horses, 12 draught horses. Besides these, a steam sapper was available. Personnel to be determined upon as required (*I. A. M.*, 1899, 1).

1890. April. Formation of a balloon depôt (Personnel: 1 inspector, 1 mechanic, 1 engineer, 6 men) and a ballooning division, consisting of 1 captain, 2 lieutenants, 1 corporal, 1 sergeant, 23 men. Balloon equipment as in 1888.

1897. Experiments on shooting at balloons, and many other experiments on the application of balloons. According to the latter, spherical balloons could not be used with a wind velocity greater than 9 m. per second.

1899/1900. Balloon Section in Boer War (*I. A. M.*, 1900, No. 1, No. 2; 1902, No. 1).

Balloon Section No. 1 (Capt. Heath) ordered to Natal (4th November). Part of it was, without material, in Ladysmith during the siege, and remained there 29 days in inactivity. Out of the part not besieged, Capt. Phillips organised a new division for Gen. Buller's army. In the night of 18/19 January 1900 they attempted to discover the position on the Tugela occupied by the Boers, with the help of search-lights. In use during the battles of

1899/1900. Vaalkrantz, Spion Kop, and Springfontein. On the 10th February the balloon was shot down by the Boer artillery.

Balloon Section No. 2 (Capt. Jones, Lieuts. Grubb and Earle) ordered to Cape Town to join Lord Methuen's army. Ascent on 11th December before Magersfontein, lasting until 15th December, when the anchored balloon broke loose in a storm. Accompanied Lord Roberts to Paardeburg. Discovered the position of General Cronje's laager (24th February). The artillery fire was directed among the waggons of the Boers by observations taken from balloons. The observations extended over five days, during which the balloon was continually fired at. Constant readiness for use during the march of Lord Roberts to Pretoria.

Balloon Section No. 3. (Lieut. Blakeney) set off for Kimberley and Mafeking in March. Chief use by Fourteen Streams, where the balloon remained inflated for 13 days.

1900. A Fourth Balloon Section (Lieut.-Col. Macdonald) ordered (14/8) to China to join the expedition there, but arrived too late.

1902. Organisation of 1 depôt and 6 sections.

1904. Formation of a balloon establishment at Aldershot.

1905. Numerous ascents made from Aldershot in kites under the direction of Mr F. S. Cody. Men were frequently raised to altitudes of over 3000 ft. (*cf.* Baden-Powell, "The Advent of the Flying Machine," *National Review*, May 1906).

§ 9. ITALY.

1885. Purchase of balloon stores from Yon's of Paris, consisting of 1 steam winch, with 500 m. hemp cable (fig. 79); 1 gas generator for the production of hydrogen by the action of sulphuric acid on iron filings (giving 130 cb. m. per hour); 1 balloon waggon. Balloon of ponghée-silk, of 536 cb. m. contents. Car in trapeze suspension. The organisation of a War Balloon Division followed, the personnel consisting of 1 captain or lieutenant as conductor, 1 first lieutenant or second lieutenant, 1 corporal or sergeant, 3 sergeants, 1 trumpeter, 40 men.

Train: 1 sergeant or corporal, 2 corporals, 30 men. Total—2 officers, 50 aeronauts, 33 transport soldiers. 3 riding horses, 1 steam winch (2500 kg.) for 4 horses, 1 gas generator (2600 kg.) for 6 horses, 1 balloon waggon (2000 kg.) for 4 horses, 3 sulphuric acid waggons, 12 horses, 3 transport waggons C/76, 12 horses, 1 battalion car, 2 horses, 2 horses in reserve. Total—3 riding, 40 draught, and 2 reserve horses.

1885. Arrangement of an experimental station under Graf Pecori Geraldi, of the 3rd Regt. of Engineers, in Fort Tiburtina near Rome. According to the law of 23rd October 1887, the 3rd Regt. of Engineers received a special company, to which was given the charge of the balloon service (G. de Rossi, *la Locomozione aerea applicazioni in tempo di guerra*. Lanciano, 1887).

1887. July-Aug. Successful participation in the manœuvres near Verona.

Nov. Light balloon stores on the English system procured (2 balloons of gold-beaters' skin of 140 and 200 cb. m. contents respectively, and 200 steel cylinders of com-

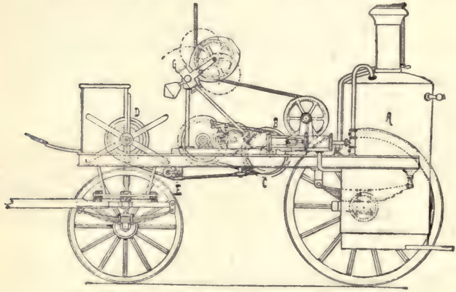


FIG. 79.—Steam winch for captive balloons (Yon).

pressed gas from Nordenfelt's. Two silk balloons of 260 cb. m. and 310 cb. m. contents ordered, in addition to several smaller balloons of 50 cb. m. contents, a hand winch, and stationary gas generator, from Paris.

Organisation of a Light Balloon Division for Abyssinia under Count Pecori. Sailed on 4th December (6 officers, 4 sections of engineers). A fixed station erected in the ort Abd-el-Kader, near Massaua, with arrangements for preparing and compressing gas.

1888. Jan. Expedition to the interior. Stores consisted of 1 balloon waggon with hand winch, 40 gas cylinders loaded on 20 camels.

Feb. Arrival at Saati. Successful ascent to a height of 500 m.

1890. Participation of a ballooning section, of strength 2

officers, 58 men, 5 waggons, and 23 horses, in the manœuvres (*cf.* v. Löbell's *Jahresberichte*, 1892).

1895. Participation by 3 balloon sections in the royal manœuvres near Aquila.

Organisation.—Fort stores (parco da fortezza): balloon 10 m. diameter, of varnished silk (528 cb. m.). Car for 2 observers, trapeze suspension, hempen cable 509 m. in length, telephonic connections.

1 balloon waggon; 1 hand winch; 1 portable gas generator, Yon's system, giving 100–120 cb. m. per hour; material necessary for the production of 1 cb. m. hydrogen: 3 kg. iron filings, 9 kg. sulphuric acid, 60 litres water.

Field stores (parco da campagna): 1 balloon waggon; 1 hand winch; 6 gas waggons, each with 30 gas cylinders 2·44 m. long, 145 mm. diameter, weighing 40 kg., and holding 3·7 cb. m. hydrogen at 120 atm. pressure. In addition, each equipment had, further, 2 echelons each of 160 gas cylinders. Balloon filled from 5 gas waggons in 1½ hours (*cf. Manuale per l'Ufficiale del genio in guerra.* Rome, 1895).

1900. Introduction of kite-balloons for signalling purposes in the navy.

1901. Introduction of a kite-balloon of the Parseval-Sigsfeld type (600 cb. m.), obtained from A. Riedinger of Augsburg, for the balloon stores.

1903. The organisation of the Balloon Troops was at length completed. In case of war, 6 light and 2 heavy ballooning sections, with in all 22 officers and 628 men, are available.

§ 10. FRANCE.

1783. 9 Oct. Giroud de Vilette ascended in the captive Montgolfière from the Rue de Montreuil, and wrote on the 20th November concerning the ascent: "Dès l'instant je fus convainçu, que cette machine seroit très-utile dans une armée pour découvrir la position de celle de l'ennemi, ses manœuvres, ses marches, ses dispositions, et les announcer par des signaux. Je crois, qu'en mer, il est également possible avec des précautions, de se servir de cette machine."

1793. 13 Aug. Guyton de Morveau proposed to the Convention the use of captive balloons in war. A commission was appointed to carry out trials in the Jardin des Feuillants in the Tuileries.

25 Oct. Decision of the Convention to use the balloon im-

mediately, in the Moselle army under General Jourdan (Capt. Coutelle, Lieut. L'homond).

24 Nov. Coutelle's proposals for improvements were accepted by the Convention at the suggestion of Carnot. Conté was associated with Coutelle, and Meudon decided upon as the site for the experimental station.

1794. 2 Apr. Formation of a Balloon Division to provide the necessary staff and stores, as well as to carry out further experiments at Meudon under Conté's direction.

2 June. First ascent by the 1st Company of Aérostiers near Maubeuge (Capt. Coutelle, First Lieut. L'homond. Balloon: "l'Entreprenant," 27 ft. diameter, or about 300 cb. m. contents).

23 June. The Balloon Division in Meudon was brought up to the staff of a company (Company of Aérostiers).

23–25 June. Ascents near Charleroi.

26 June. Ascent during the battle of Fleurus.

14–18 Sept. Experiments by the 1st Company of Aérostiers with the cylindrical-shaped balloon "Martial" in Brussels. March through Lüttich to winter-quarters in Burtscheidt.

31 Oct. The committee of public safety founded, at Coutelle's suggestion, "L'École nationale aérostatique de Meudon," under Conté's direction, to serve to furnish the troops with recruits and to provide their arsenals with balloon stores. The school—Director Conté, Assistant-director Bouchard—accommodating 60 aérostiers divided into 3 sections of 20 men each; each section had 1 lieutenant, 1 sergeant, 2 corporals, 1 drummer, and 1 magazine steward.

1795. 23 Mar. Mobilisation of two companies of aérostiers under the direction of Coutelle, recalled from Burtscheidt. Coutelle was appointed Chef de Bataillon and Commandant. The personnel of each company was increased to 1 captain, 2 lieutenants, 1 lieutenant-quartermaster, 2 sergeants, 1 veterinary surgeon, 3 corporals, 1 drummer, 44 men.

1*st Company.* —Capt. L'homond, Lieut. Plazanet, Lieut. Gancel, Quartermaster-Lieut. Varlet. Balloons: "l'Intrépide," "l'Hercule."

2*nd Company.*—Capt. Delaunay, Lieut. Merle, Lieut. De Selle de Beauchamp, Quartermaster-Lieut. Deschard. Balloon: "l'Entreprenant."

April. The 2nd Company proceeded, under Coutelle, to join General Pichegru's Rhine army; arrangement of the stores in Kreuznach. Ascents during the siege of Mayence. Winter quarters in Frankenthal, transferred later to Molsheim i/E.

1796. The 1st Company, with General Jourdan's army, made ascents in front of Andernach and Ehrenbreitstein (1–7 August) and were taken prisoners by Duke Karl's Austrian army at Wurzburg (4th September).

The 2nd Company, with General Moreau's army, marched from Molsheim i/E, through Strassburg, Rastadt, Stuttgart (ascent), Donauwörth (reconnoitring), to Augsburg. On the return, through Rastadt, they went to Molsheim, where they remained.

1797. Capitulation at Loeben (7th April). (Gen. Bonaparte.) The 1st Company was released from captivity.

The 2nd Company lay inactive in Rupprechtsau, near Strassburg i/E.

1798. The 1st Company, including Coutelle and Conté, ordered to Egypt. Destruction of the balloon materials in the naval battle near Abukir (1st and 2nd August). The Aérostiers sent up several Montgolfières from forts in Cairo (22/9 and 11/11, 1798, and 14/1, 1799), and were otherwise in requisition.

(*Cf.* Baron Marc de Villiers du Terrage, *Les Aérostiers militaires en Égypte, camp. de Bonaparte, 1798–1801.* Paris, 1901.)

1799. 18 Jan. Disbandment of the balloon companies according to the following decree:—

Paris, le 14 Ventôse an VII^{e} de la République française, une et indivisible.

Le Ministre de la guerre.

Au général en chef de l'armée de Mayence.

Je vous adresse ci joint, Citoyen général copie en forme d'un arrêté du Directoire Exécutif, du 29 du mois d^{er}, qui supprime les Compagnies d'Aërostiers. Je vous invite à donner des ordres pour que cet arrêté soit exécuté à l'égard de la 2^{e} Compagnie d'Aërostiers, qui se trouve à l'armée, que vous commandez.

Salut et Fraternité,
MILET-MUNEAU.

Ampliation.

Extrait des Registres du Directoire Exécutif, du vingt neuf Pluviôse de l'an VII^{e} de la République Française, une et indivisible.

Le Directoire-Exécutif, sur le rapport du Ministre de la guerre, arrêté :—

Art^e. 1.

1799. 18 Jan. Les officiers, Sousofficiers et soldats, des Compagnies d'Aërostiers, seront supprimés à la date du 1er germinal prochain.

Art^e. 2.

Les soldats de l'Age de la réquisition où de la conscription attachés à ces compagnies seront de suite incorporés dans les Bataillons de Sapeurs les plus à portée du lieu de garnison, ceux que ne seront ni conscripts ni réquisitionnaires seront libres de se retirer dans leurs foyers.

Art^e. 3.

Les Sousofficiers des compagnies d'Aërostiers seront placés dans leurs grades à la suite des nouvelles demie Brigades, s'ils n'aiment mieux se retirer dans leurs foyers, dans le cas où ils ne seraient ni conscripts ni réquisitionnaires.

Art^e. 4.

Il sera statué sur le traitement de réforme des officiers.

Art^e. 5.

Le Ministre de la guerre est chargé de l'exécution du présent arrêté, que ne sera pas imprimé.

Pour Expédition conforme :—

Le Présid^t. du Directoire-Exécutif, Signé L. M. Reveillere-Lepeaux ; Par le Directoire-Exécutif, le Secrétaire Général, Signé Lagarde.

Pour copie conforme,
Le Ministre de la guerre,
MILET-MUNEAU.

1801. Pluviôse de l'an X. Disbandment of the 1st Company in Marseilles on their return from Egypt.

1859. Lieut. Godard, engaged for the Campaign, made ascents in a small Montgolfière in Milan, Gorgonzola, Castenedolo, and Castiglione. In Castiglione he detected an attempt of the adversaries to delay the advance of the enemy by driving the flocks towards them and thus blocking all the roads. Later he made ascents at the blockade of Peschiera.

1870. Organisation (4th September) of 3 captive balloon stations in Paris under Col. Usquin: Nadar, on the Place Saint Pierre—"Le Neptune"; Wilfrid de Fonvielle, in the gas-works at Vaugirard—"Le Céleste," 750 cb. m. ;

1870. Eugen Godard, on the Boulevard des Italiens—"Ville de Florence."

Small balloons with soldiers' letters sent away from Metz (16th and 17th September). Letters: light tickets 6×9 sq. cm., each balloon taking 5000.

Organisation of the balloon post in Paris by General Post-Director Rampont. Between 23rd September 1870 and 28th January 1871, 65 balloons carrying 164 persons, 381 carrier pigeons, 5 dogs, and 10,675 kg. post material left Paris.

The balloons were prepared by Eugène Godard on the Orleans Station, and by Yon in conjunction with Camille d'Artois on the Nord Station.

Size of balloons, 2000 cb. m. Material—varnished cambric. Ten hours after the inflation had still 500 kg. lifting power. Each balloon, including the remuneration of the aeronaut, cost 4000 francs.

(*Cf.* Steenackers, *Les Télégraphes et les Postes pendant la guerre de 1870–71* (Paris, 1883); G. Tissandier, *En Ballon pendant le siège de Paris* (Paris, 1871).

Before sending away each balloon the meteorologist, Hervé Mangon, was consulted.

Balloon letters.—Usual weight, 4 gm.—postage, 20 centimes; carte poste, 11 cm. long, 7 cm. wide—postage, 10 centimes (*Journal Officiel de Paris*, 27/9/'70).

Introduction of the microphotographical pigeon post despatches, for cloudy weather (10th November). Cards for replies to four questions to be answered with Yes or No. Printed cards, 5 centimes; postage, 1 franc. Words despatched, 50 centimes each.

Out of 302 pigeons sent back to Paris 59 reached their destinations with despatches. The microphotographical despatches were improved greatly after Dagron's arrival in Bordeaux.

A film 38×50 mm. in size contained 2500 messages. The pigeons usually carried 18 films with 40,000 messages.

246 official and 671 private despatch films were sent away from Paris in 61 feather quills.

The numbers of persons engaged in preparing the messages, etc., in Paris numbered 67.

95,581 telegrams were received in the provinces, of which more than 60,000 reached Paris. The receipts for the same reached the sum of 432,524 francs, 90 centimes.

LIST OF BALLOONS WHICH

Ascent.			Name of Balloon.	Size of Balloon in cb. m.
Date.	Time.	Place.		
23/9	8 a.m.	Montmartre	Le Neptune	1200
25 ,,	11 ,,	Boulevard d'Italie	La Ville de Florence	1400
29 ,,	10.30 ,,	La Villette Gas-works	Le Napoléon	800
			L'Hirondelle (Les États Unis)	540
30 ,,	9.30 ,,	Vaugirard Gas-works	Le Céleste	780
7/10	11 ,,	Place St Pierre	L'Armand Barbés	1200
,, ,,	,, ,,	,,	Le George Sand	1200
9 ,,	2.45 p.m.	La Villette Gas-works	(Unnamed)	1200
12 ,,	9 a.m.	Montmartre	Le Louis-Blanc	1200
,, ,,	8.30 p.m.	Orleans Station	Le Washington	2000
14 ,,	10 a.m.	,,	Le Godefroy-Cavaignac	2000
,, ,,	1 p.m.	,,	Le Guillaume-Tell	2000
16 ,,	7.30 a.m.	,,	Le Jules Favre	2000
,, ,,	9·50 ,,	,,	Le Jean Bart	2000
18 ,,	12 noon	Jardin des Tuileries	Le Victor Hugo	2000
19 ,,	9.15 a.m.	Orleans Station	Le République Universelle (Le Lafayette)	2000
22 ,,	11.30 ,,	Jardin des Tuileries	Le Garibaldi	2000
25 ,,	8.30 ,,	Orleans Station	Le Montgolfier	2000
27 ,,	9 ,,	,,	Le Vauban	2000

LEFT PARIS, 1870–71.

Balloon Conductor.	No. of Passengers.	No. of Carrier Pigeons.	Post-bags —kgs.	Time and Place of Landing, and Remarks.
Duruof	...	...	125	11 a.m.; Craconville near Evreux.
Mangin	1	3	150	5 p.m.; Vernouillet near Triel (S. et O.).
Louis Godard	1	4	80	1 p.m.; Mantes (S. et O.).
G. Tissandier	...	3	80	Noon; Dreux (Eure-et-Loire); threw proclamations out.
J. Trichet	2 (Gambetta & Spuller)	16	100	3.30 p.m.; Mondidier; Gambetta was wounded in the hand over Creil.
J. Revilliod	3	18	...	4 p.m.; Creméry near Roye (Somme).
Racine	2	...	...	3.15 p.m.; Fort de la Courneuve.
Farcot	1	8	125	Noon; Beclère in Belgium.
Bertaux	2	25	300	About midnight; Carnières near Cambrai.
Godard père	3	6	200	About 4 p.m.; Brillon (Meuse).
A. Tissandier	2	10	300	In the night; Montpothier near Nogent-sur-Seine.
L. Godard jeune	3	6	195	Noon; Foix de Chapelle (Belgium).
Labadie	2	4	300	1 p.m.; Évrechelles (Belgium).
Nadal	...	6	440	5.30 p.m.; Vaubécourt near Bar-le-Duc.
Jossec	2	6	300	11.30 a.m.; near Rocroi (Ardennes).
Iglesia	1	6	450	1.30 p.m.; Quincy-Segy near Meaux (Seine-et-Marne).
Hervé-Sené	2	2	390	1 p.m.; Holligemberg (Holland).
Guillaume	2	23	270	1 p.m.; Verdun (Meuse).

LIST OF BALLOONS

Ascent.			Name of Balloon.	Size of Balloon in cb. m.
Date.	Time.	Place.		
27/10	12 noon	La Villette Gas-works	La Bretagne (La Normandie)	1650
29 ,,	12 ,,	Nord Station	Le Colonel-Charras	2000
2/11	8.30 a.m.	Orleans Station	Le Fulton	2000
4 ,,	9 ,,	Nord Station	Le Ferdinand Flocon	2000
,, ,,	2 p.m.	,,	Le Galilée	2000
6 ,,	10 a.m.	,,	La Ville de Châteaudun	2000
8 ,,	8.30 ,,	Orleans Station	La Gironde	2000
12 ,,	9.15 ,,	,,	La Daguerre	2000
,, ,,	,, ,,	,,	La Niepce	2000
18 ,,	11.15 p.m.	Nord Station	Le Général Uhrich	2000
21 ,,	1 a.m.	Orleans Station	L'Archimède	2000
24 ,,	11.40 p.m.	Nord Station	La Ville d'Orléans	2300
,, ,,	10 a.m.	Vaugirard Gas-works	L'Égalité	3000
28 ,,	11 p.m.	Orleans Station	Le Jacquard	2000
30 ,,	11.30 ,,	Nord Station	Le Jules Favre No. 2	2000
1/12	5.15 a.m.	,,	La Bataille-de-Paris	2000
2 ,,	6 ,,	Orleans Station	Le Volta	2000

Note.—On 21st November

—continued.

Balloon Conductor.	No. of Passengers.	No. of Carrier Pigeons.	Post-bags —kgs.	Time and Place of Landing, and Remarks.
Cuzon	3	...	...	3 p.m. ; Dep. Meuse ; balloon captured, and two passengers taken prisoners.
Gilles	...	6	460	5 p.m. ; Montigny (Haute Marne).
Le Gloennec	1	6	350	2.30 p.m. ; La Jumellière (Marne-et-Loire).
Vidal-Loisset	1	6	150	4 p.m. ; near Château-briant (Loire-inférieure).
Husson	1	6	400	6 p.m. ; near Chartres ; captured. The passengers escaped.
Bosc	...	6	455	5 p.m. ; Reclainville (Eure-et-Loire).
Gallay	3	3	60	3 p.m. ; Grainville (Eure).
Jubert	2	30	260	11 a.m. ; Jossigny (Seine-et-Marne) ; captured.
Pagano	4 Dagron	..	... Phot. App.	2.30 p.m. ; Vitry-le-François (Marne).
Lemoine	3	34	80	19/11, 8 a.m. ; Luzarches (Seine-et-Oise).
J. Buffet	2	5	300	6.40 a.m. ; Castelré (Limbourg), Holland.
Rolier	1	6	250	25/11, 2.25 p.m. ; Mont Lid (Norway).
Wilfrid de Fonvielle	4	12	...	2.15 p.m. ; near Louvain (Belgium).
Prince	...	...	250	Seen at Plymouth. Disappeared.
Martin	1	10	100	1/12, 8.30 a.m. ; Belle Isle-en-Mer.
Poirrier	2	...	...	12 noon ; Grand-Champ near Vannes (Morbihan).
Chapelain	1 Janssen	...	...	11.30 a.m. ; Savenay (Loire-inférieure).

private carrier pigeons were taken.

LIST OF BALLOONS

Ascent.			Name of Balloon.	Size of Balloon in cb. m.
Date.	Time.	Place.		
5/12	1 a.m.	Orleans Station	Le Franklin	2050
7 ,,	6 ,,	Nord Station	L'Armée-de-Bretagne	2000
8 ,,	1 ,,	Orleans Station	Le Denis-Papin	2000
11 ,,	2.15 ,,	Nord Station	Le Général Renault	2000
15 ,,	4.45 ,,	,,	Le Ville-de-Paris	2000
17 ,,	1.15 ,,	Orleans Station	Le Parmentier	2050
,, ,,	1.30 ,,	,,	Le Guttemberg	2045
18 ,,	5 ,,	,,	Le Davy	1200
20 ,,	2.30 ,,	Nord Station	Le Général-Chanzy	2000
22 ,,	2.30 ,,	Orleans Station	Le Lavoisier	2000
23 ,,	4.30 ,,	Nord Station	Le Déliverance	2050
24 ,,	3 ,,	Orleans Station	Le Rouget de d'Isle	2000
27 ,,	4 ,,	,,	Le Tourville	2045
29 ,,	4 ,,	,,	Le Bayard	2045
30 ,,	5 ,,	Nord Station	L'Armée-de-la-Loire	2000
,, ,,	4 ,,	,,	Le Merlin-de-Douai	2000
1871 4/1	4 ,,	Orleans Station	Le Newton	2000
9 ,,	3.15 ,,	,,	Le Duquesne	2000
10 ,,	4 ,,	Nord Station	Le Gambetta	2000
11 ,,	3.30 ,,	Orleans Station	Le Kepler	2000

—continued.

Balloon Conductor.	No. of Passengers.	No. of Carrier Pigeons.	Post-bags —kgs.	Time and Place of Landing, and Remarks.
Marcia	1	6	100	8 a.m. ; near Nantes (Loire-inférieure).
Surel de Montchamps	1	6	400	2 p.m. ; Bouillé (Deux-Sèvres).
Domalin	3	3	55	7 a.m. ; near Mans (Sarthe).
Joignerey	2	12	100	6.30 a.m. ; Baillotet (Seine-inférieure).
Delamarne	2	12	65	1 p.m. ; Wetzlar (Prussia) ; captured.
Paul	2	4	160	9 a m. ; Gourgançon near Fère-Champenoise (Marne).
Perruchon	3	6	...	9 a.m. ; Montépreux near Fère-Champenoise (Marne).
Chaumont	1	...	50	12 noon ; near Beaune (Côte d'Or).
Werecke	3	4	25	10.45 a.m. ; Rothenburg (Bavaria) ; captured.
Ledret	1	5	175	9 a.m. ; Beaufort (Maine-et-Loire).
Gauchet	1	4	110	11.45 a.m. ; La Roche-Bernard (Morbihan).
Jahn	2	...	...	9 a.m. ; Alençon (Orne).
Moutet	2	4	160	1 p.m. ; Eymoutiers (Haute-Vienne).
Reginensi	1	4	110	10 a.m. ; Lamothe-Achard (Vendée).
Lemoine	...	...	250	1 p.m. ; in Gen. Chanzy's camp near Le Mans (Sarthe).
Griseaux	1	...	...	11.45 a.m. ; Massay near Vierzon (Cher).
Ours	1	4	310	12 noon ; Digny (Eure-et-Loire).
Richard	3	4	150	3 p.m. ; Berzieux (Marne).
Duvivier	1	3	240	2.30 p.m. ; Avallon (Yonne).
Roux	1	3	160	10.15 a.m. ; Laval (Mayenne).

List of Balloons

Ascent.			Name of Balloon.	Size of Balloon in cb. m.
Date.	Time.	Place.		
13/1	3.30 a.m.	Nord Station	Le Général Faidherbe	2000
14 ,,	1 p.m.	Orleans Station	Le Monge	2000
15 ,,	3 a.m.	,,	Le Vaucanson	2000
16 ,,	7 ,,	Nord Station	Le Steenackers	2000
18 ,,	3 ,,	,,	Le Poste-de-Paris	2000
20 ,,	5 ,,	,,	Le Général Bourbaki	2000
22 ,,	4 ,,	Ost Station	Le Général Daumesnil	2000
24 ,,	3 ,,	,,	Le Toricelli	2045
27 ,,	3.30 ,,	Nord Station	Le Richard Wallace	2000
28 ,,	6 ,,	Ost Station	Le Général Cambronne	2000

1870. Dupuy de Lôme, marine engineer, received an order to build an air-ship for the traffic communication of the Government with the outer world; 40,000 francs were allotted to him for this purpose (*Journ. Officiel*, 28/10/'70).

The brothers G. and A. Tissandier attempted, in November, to journey by balloon from Rouen to Paris with a favourable wind.

The Government at Tours organised a Balloon Division (December) from among the aeronauts who had succeeded in leaving Paris. Two divisions were formed under G. Tissandier and J. Revilliod, each with 150 soldiers of the guard and 2 balloons.

Arrangement of the stores (under Durnof and Mangin) in Tours.

—continued.

Balloon Conductor.	No. of Passengers.	No. of Carrier Pigeons.	Post-bags —kgs.	Time and Place of Landing, and Remarks.
Van Seymortier	1	2	60	2 p.m.; Saint Avid-de-Soulège (Gironde).
Raoul	2	...	...	8 a.m.; Arpheuilles near Mezières-en-Brennes (Dept. de l'Indre).
Clariot	2	3	75	10.15 a.m.; near Armentières (Belgium).
Vibert	1	1	Dynamite.	11 a.m.; Hynd on the Zuydersee (Holland).
Turbiaux	2	3	70	Evening; Venray, Limburg (Holland).
Mangin	1	4	180	11 a.m.; near Reims.
Robin	...	3	280	8 a.m.; Charleroy (Belgium).
Bely	...	3	230	11 a.m.; Fumechon (Oise).
Lacaze	...	3	220	Seen near Niôrt and Angoulême, and finally at a considerable height above La Rochelle going towards the ocean; lost.
Tristan	...	...	20	1 p.m.; near Mayenne.

1870. The improvised balloon division succeeded in no useful, practical object under the changing conditions of the war.

1874. May. A "Commission des aérostats militaires" called under Col. Laussedat to study ballooning.

1875. 8 Dec. Bursting and disastrous descent of one of the balloons, "l'Univers," belonging to the Commission.

1877. Formation of a Balloon Division in Meudon: 1 officer (Capt. Renard), 1 sergeant, 4 pioneers, 1 civil aeronaut (Adrien Duté-Poitevin), 1 basket-maker. Later, Capt. de la Haye joined also.

Stores.—One balloon, "La Sentinelle." Renard devised his method of suspending and fastening the French captive balloon (fig. 34).

1878. On Gambetta's proposition, 200,000 francs were allotted for the provision of a navigable air-ship; but only 50,000 francs were offered for this purpose by Col. Laussedat. Capt. Krebs took the place of Capt. de la Haye.

1879. Inspection of Meudon by Gambetta. Construction of a steam winch.

1880. Order to provide 8 captive balloon stores, and to form the same number of balloon sections, and to build a navigable balloon. Capt. Paul Renard attached to the section. Increase of personnel. Improvement of all arrangements.

1880/2. Buildings erected. Stores procured for four balloon divisions. Inspection of work by the Minister of War, Gen. Billot. New material sanctioned for a navigable air-ship. Test of the captive balloon equipment during the great manœuvres.

The balloon stores comprised 1 steam winch, 2 gas generators, 1 balloon material waggon, 1 coal waggon, and various carts to deal with the gas material "gazëine."

The gas generators consisted of 10 iron retorts in an oven. The gazëine was heated in the retorts (2 m. long) in the oven in pieces 30 cm. long and 5 cm. in diameter. Hydrogen was given off as soon as it became sufficiently heated. 3 kg. gazëine gave 1 cb. m. gas. Rate of development with the 2 gas generators, 500 cb. m. in 10 hours. One apparatus gave 38–50 cb. m. hydrogen per hour; the cost was 5·80 francs per cb. m.

1884. Formation of a company of aérostiers from the 1st Eng. Regt., of strength 2 officers (Capt. Aaron), 5 non-coms., 8 corporals, 23 men, for service in Tonkin. Formation of a light balloon train, 4 balloons of 260 cb. m. each. Embarkment at Hanoi.

8 Mar. March of 30 artillerymen, strengthened by 24 coolies, to Bac-Ninh; battle near Trung-Son.

6 Apr. Departure with the Négrier brigade to Hong-Hoa.

11 Apr. Battle of Hong-Hoa.

1885. Expedition against Lang-Son.

19 Jan. Departure to obtain water, to Phu-Lang-Thuong.

23 Jan. Arrival there.

29 Jan. To Kep.

30/31 Jan. Reconnoitring and Demonstration.

1884/5. Experiments with the navigable air-ship "La France" (*cf.* Chapter XII., § 2).

Date.	Actual Velocity of the Balloon in m/sec.	Result of Experiments.
9 Aug.	4·58	Return to the starting-point, Chalais.
12 Sept.	5·45	Landing near Velizy.
8 Nov.	6·00	Return to Chalais.
8 Nov.	3·82	,, ,,
1885.		
25 Aug.	6·00	Strength of wind 6·5–7 m/sec., landing in Villacoublay.
22 Sept.	6·00	Return to Chalais.
23 Sept.	6·22 (6·50)	,, ,,

"Le ballon électrique 'La France,' n'a jamais eu d'autre objet, que de fournir une première démonstratim de la possibilité de faire évoluer un ballon allongé dans l'océan aérien par des moyens analogues à ceux qui permettent aux navires marins d'évoluer sur l'océan liquide."—RENARD.

1886. Introduction of a gas generator for the balloon stores, depending in principle on the action of sulphuric acid on iron.

19 May. Decree of the President of the Republic under Boulanger's Ministry concerning the service of the military balloon troops in Chalais-Meudon. The "Établissement Central d'Aérostation Militaire" made a study of military ballooning, the construction and preservation of the materials, and the instruction of the staff of each regimental school of the four regiments of engineers at Versailles. Stores were fnrnished to Grenoble, Arras, Montpellier, and several fortresses (Toul, Epinal, Belfort, and Gray). One company out of each of the four regiments of engineers was instructed in ballooning. The balloon service, as well as the conduction of the establishment, was placed under the Minister for War. (B.O. *Cf.* de

26 June. Graffigny, *Traité d'Aérostation.* Paris, 1891.)

1887. Improvement in the steam winch and gas generator. Decree on the administration of the telegraph service

1887. 26 June. and military ballooning (*cf. Z. f. L.*, 1888, p. 22). The ballooning was placed under the director of military telegraphy. Expenses and new apparatus were considered by the Minister of War on the recommendation of the director of military telegraphy. The balloon stores and buildings were placed in charge of the engineers. The material was tested annually by an officer from Chalais-Meudon.

1 Aug. Ministerial decree. The men who have received instruction in the art of ballooning (independent of the weapons carried) shall wear, as a sign, a balloon in scarlet red cloth on the right sleeve in the middle of the arm above the elbow. (B.O. *Z. f. L.*, 1888, p. 23.)

1888. Improvement of the steam winch and the gas generator. The gas generator had two copper generating retorts, acid vats, and scrubbers. Rate of production of gas—120 cb. m. per hour per retort. Total time for inflating a "ballon normal," 3½ hours, for which 122 bottles of acid are necessary. The latter were made of copper or steel; 1 cb. m. gas cost 1·20 francs. Steam winch (see fig. 80). Behind are vertical steam boilers, in the middle a pulley for the cable, in front the cable drum with a hempen cable 500 m. in length, and underneath the latter is the winding mechanism, and on each side a steam engine working on the same axis. The field stores consisted, in addition, of a balloon waggon (voiture aux agrès) holding two normal balloons, each of 536 cb. m. contents; one other balloon (260 cb. m.); a gas bag of 62 cb. m., the tender waggon (voiture fourgon) holding about 1 cb. m. coal and 300 litres water; and a number of waggons for gas materials.

1888. Personnel of the War Balloon Division: 2 officers, 94 men; 35 horses, 7 waggons.

17 Apr. Publication of rules concerning the instruction of aérostiers. Officers in the balloon sections to study the sections de campagne, sections de forteresse, and sections de dépôt. In addition, instruction of the General Staff officers in the use of balloons.

Course for administrative officers, 1–15 June.

Free voyages required the permission of the Minister for War. Course for officers of the engineering companies (Compagnies d'Aérostiers) and officers of the General Staff, from 16–30 June.

Experiments with compressed gas in steel cylinders of 35 litres capacity and 52 kg. weight, holding 6·281 cb. m. gas at 200 atm. pressure.

Lieut. z. See Serpette and Marine Engineer Aubin

1888. sent to Chalais-Meudon to study the possible use of balloons in the navy.

12–17 July. Experiments in Toulon on board the *Indomptable.* Satisfactory results. Formation of naval balloon stores at Lagoubran. Yearly participation in the great manœuvres.

1889. Preparations for the Paris Exhibition. (Account in *Aérostats et aérostation militaire à l'Exposition Universelle de 1889*, by G. Yon and E. Surcouf. Paris, 1893.) Experiments on the preparation of hydrogen by electrolytic methods.

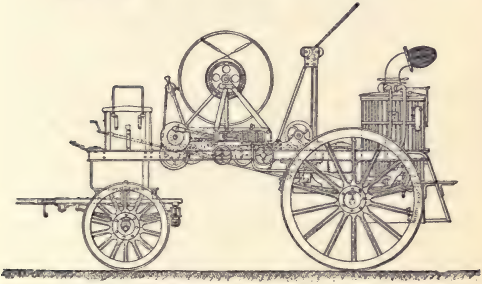


FIG. 80.—Steam winch. French Ballooning Division.

1890. Strength of a Section d'aérostiers de campagne: 1 captain, 1 lieutenant, 1 reserve-officer, 5 non-coms., 8 corporals, 3 master mechanics, and 62 rank and file. In addition, for the teams: 1 quartermaster, 1 maréchal de logis, 1 brigadier, and 28 drivers.

The stores comprised:—

1 steam winch (2100 kg.) for . . .	6	horses
1 tender waggon (laden, 2250 kg.) for .	4	,,
1 balloon waggon (1600 kg.) for . .	4	,,
1 gas generator (2400 kg.) for . . .	6	,,
2 waggons for chemicals (2100 kg.) for .	6 4	,, ,,
2 provision waggons (1400 kg.) for . .	2 2	,, ,,

In addition, 8 waggons each for 2 horses were required

1890. for the transport of chemicals. Total—16 waggons, 50 draught horses, 6 riding horses. Length of procession, 250 m.; time taken to pass any point, 3 minutes.

An agitation was set on foot to provide a balloon division for each army corps, making 20 in all.

A *Section d'aérostiers de place* consisted of 1 captain, 1 reserve officer, 5 non-coms., 8 corporals, 53 men. Also for the team, 1 brigadier and 14 drivers.

The forts have old balloon stores. The stores comprise waggons as above but no waggons for chemicals, and only 1 one-horse provision waggon. (*Cf. Aide-Mémoire de l'Officier d'État, Major en campagne, 1890.*) The free balloons for the forts for hydrogen are of 900 cb. m. contents.

Discovery of a form of voltameter for the manufacture of hydrogen, applicable to industrial purposes, by Renard. 1 cb. m. gas costs 60 centimes. Trial introduction of a hydrogen waggon with compressed gas in the balloon train. Each waggon contained 8 steel cylinders each 4·50 m. long and 0·30 m. in diameter, laid in 2 rows on the waggons. Each cylinder was tested under a pressure of 300 atm., and weighed 250 kg. empty. Weight of waggon, 3000–3200 kg. A waggon held 280 cb. m. gas compressed under 220 atm. For use in time of peace not more than 130 atm. was to be used.

Participation of a field balloon equipment of war strength, with a diminished number of horses and waggons, in the great manœuvres. Division into 2 echelons.

1st Echelon: 3 officers, 5 non-coms., 60 corporals and rank and file, 1 quartermaster, 18 drivers.

1 steam winch, 1 tender waggon, 1 balloon waggon, 3 gas waggons, 1 provision waggon, 1 forage waggon.

2nd Echelon: 1 officer, 1 sergeant, 10 men (an insufficient number, according to Debureaux), 1 gas generator, 1 waggon with compression pump, 3 gas waggons. (*Cf.* Debureaux, *Les Aérostats militaires*, Paris, 1892. On the stores, *cf. Les Ballons à la guerre*, Paris, 1892; Charles Lavaurelle, extract in the *Z. f. L.*, 1893, p. 20.)

Captive balloon practice in the school of the 4th Engineers, as well as in the fortresses at Verdun, Toul, Epinal, and Belfort. Free voyages from Chalais-Meudon and Grenoble.

Arrangement of naval balloon depôts in Toulon and in Brest. Several officers and about 36 men ordered

1890. 14 days' annual practice. Balloons, 120 and 260 cb. m. contents. Greatest height attained, 400 m.

8 Dec. *Réglement sur la Fonctionnement de l'École aérostatique de Chalais* (B.O., 1890, No. 75).

Supplement to the Réglement of 17/4/'88.

Art. 1.—In addition to the officers, a certain number of non-commissioned officers and others will be educated as instructors for the companies of engineers in Chalais.

Art. 6.—The balloon officers must take part as frequently as possible in the free ascents, and, after attaining sufficient practice, may undertake independent voyages. Permission for this is granted by the Minister on the recommendation of the director of the establishment.

Art. 7.—From May 1–31, the balloon officers and the officers chosen to look after the stores to receive instruction. May 12–31: General staff officers to receive instruction. May 24–31: The principal officers commanding companies of aérostiers ordered to receive instruction in the latest improvements effected. The personnel of the establishment at Chalais-Meudon—1 major, 2 captains, 2 adjutants, and 60 sappers—was considered too small for carrying out its duties.

1891. Nov. Decision as to the introduction and use of steel cylinders of compressed gas in the ballooning equipment.

1892. A balloon inflated in twenty-six minutes (*Figaro*, 12/5/'92). Increase of the personnel in the mobile field-balloon division.

Parc de campagne.—A section consists of 1 captain as leader, 2 lieutenants, 6 non-coms.—including 1 paymaster, 8 corporals, 2 horn players, 74 rank and file of the aérostiers.

Transport.—1 quartermaster, 1 brigadier, 28 drivers, 6 saddle-horses, 52 draught horses (*cf.* Dibos, *Les aérostats dans leur utilisation militaire.* Paris, 1893).

Stores.—A normal balloon, 523 cb. m.; a second balloon, 260 cb. m. Each section had 5 gas waggons carrying 8 steel cylinders, each 4 m. in length and 0·27 m. in diameter. Contents, 36 cb. m. under 200 atmospheres pressure. The filling was carried out at Chalais-Meudon, or in the magazine stations possessing gas generators and compressing machines. For inflating the normal balloon 2 gas waggons are sufficient in war. All the sections are now provided with gas waggons; a distinction is made between "parcs à hydrogène comprime" and "parcs ordinaires."

1892. The "parcs fixes des places" consist of one fixed gas generator, a balloon shed, and a workshop.

Free balloons of 980 cb. m. are also kept in the fortresses.

1895. A section d'aérostiers was sent to Madagascar, provided with "matérial spécial," consisting of 2 captive balloons each of 200 cb. m. contents, with adjuncts, 3 steel wire-ropes 400 m. long, hydrogen sufficient for five inflations in steel gas-cylinders.

1897. Experiment with a balloon sent out from Paris followed by cyclists, the supposition being that the town was in a state of siege and the cyclists belonged to the besieging army. 46 cyclists followed the balloon for 2½ hours and took the passengers prisoners on landing (*La France militaire*, No. 3933).

1900. 22 Aug. A section d'aérostiers sent to Taku. Personnel: 1 captain (Lindecker), 2 lieutenants (Plaisant and Izard), 7 non-coms., 72 sapeurs-aérostiers, 11 sapeurs-conducteurs; 15 mules. Matérial spécial as in 1895. Some of the transport material did not arrive.

Arrival in Taku 1/10; disembarkment concluded 13/10. Ordered to Tientsin.

Nov. Ascents in Tientsin; no military object.

1901. Ascents in Pekin. Photographs taken.

Mar. Return to France, 10th May.

30 Mar. Introduction of a new "Réglement sur l'instruction du bataillon d'aérostiers," on the basis of the Réglement of 16/2/1900. Detailed instructions for officers and men in all branches of service.

1 Apr. (*Décret*, 21/1/'01.) New organisation of the engineers; the "Compagnies d'aérostiers," hitherto joined to the single regiments of engineers, were all combined to form a balloon-battalion (bataillon d'aérostiers). The balloon battalion was named the 25th Engineer Battalion, and was divided into four companies.

The personnel of a company consists, according to the law of 9th December 1900, of 1 captain of the first class, 1 captain of the second class, 1 first lieutenant, 1 second lieutenant, 1 adjutant, 1 sergeant-major, 1 sergeant-corporal, 6 sergeants, 12 corporals, 4 company drivers, 2 trumpeters or horn players, 81 men. Total—4 officers, 27 non-coms., 81 men. (*Cf. Bulletin Officiel*, 1900 p.r., No. 51, and 1901 p.r., No. 4.)

Circulaire—6 July. *Sapeurs Aérostiers.*—The ballooning divisions act under the orders of the Chiefs of Engineers of Toul, Epinal, Verdun, and Belfort, and guard the balloon stores of these forts; they belong to the staff of the particular

1901. battalion which is stationed in the corresponding corps district. They are placed under the 25th Battalion (aérostiers) of the 1st Regiment.

Circulaire—10 Aug. Relative aux prix à décerner à la suite des concours annuels organisées dans le bataillon d'aérostiers.

The prizes for the aérostiers are divided between the *concours individuels* and the *concours collectifs*, including non-commissioned officers and troops. The rewards of the first kind are as follows:—For non-commissioned officers (*a*) preparation of a balloon for inflation; (*b*) making ready for a free or captive ascent; (*c*) taking apart and putting together again the winch; (*d*) loading the balloon waggons. For corporals and soldiers (ballooning) of first class: in sailor's, tailor's, mechanic's and preparatory work.

For *concours collectifs* the tasks under (*a*), (*b*), (*c*), and (*d*) are again given. Golden braids are given as prizes for non-commissioned officers, to be worn only until they leave active service. The corporals and men receive (with certain exception) braid of red wool, and money prizes of 2, 3, 5, or (for groups) 10 francs.

1902. As a special badge the aérostiers of the first class received the following:—Non-commissioned officers, a gold knitted anchor on the left shoulder; corporals, master mechanics, and sapeurs aérostiers, a similar badge knitted in red wool.

The straps offered as aeronautical prizes are to be worn under the above badges, in the form of a right angle, opening towards the arm between the elbow and shoulder.

Mar. Organisation of a free voyage service.

The men for this purpose are drawn from all grades and ranks of the reserve and territorial army. A test is carried out by a military aeronautical commission, embracing geography, meteorology, topography, and the art of ballooning (*I. A. M.*, 1902, No. 4). The fixed places where these "qualified aeronauts" are to be stationed are to be determined by the Minister of War.

9 June. Death of Lieut. Baudic, Director of the Établissement d'Aérostation maritime, of Lagoubran, owing to a descent in the sea (*I. A. M.*, 1902, No. 3).

Aug. Experiments on the discovery of the submarine, *Gustave Zédé*, from a captive balloon.

The position was soon discovered by the reflection of the sun on the surface waves set up by the submarine boat. Moreover, the green colour of the submarine boat

did not render it, as was anticipated, invisible (*I. A. M.*, 1902, No. 4).

1903. 13 Feb. Separation of the "Laboratoire de recherches à l'Aérostation militaire" from the "Établissement central du matérial de l'Aérostation militaire." Each establishment is to possess its own independent organisation.

1904. Disbandment of the Établissement d'Aérostation maritime of Lagoubran.

Commencement of experiments with a German kite-balloon of the Parseval-v. Sigsfeld type.

1905. Death of Col. Charles Renard.

13 Apr. Lebaudy's air-ship thoroughly tested by a Commission (consisting of Commandant Bouttiaux and Capt. Voyer) appointed by the Minister for War.

3 July. Voyage from Moisson to Meaux, 91 km., in 2 hrs. 37 mins. Reinflated with hydrogen.

4 ,, Voyage from Meaux to Sept-Sorts, 12·7 km. in 47 mins. Anchored in a building owing to the stormy weather.

6 ,, Voyage from Sept-Sorts to Mourmelon, near Chalons, 93·12 km. in 3 hrs. 21 mins. After the landing the balloon burst by striking a tree. It was taken to Toul and repaired.

8 Oct. Commencement of new trials in Toul. These were highly successful.

12 ,, The Minister for War (M. Berteaux) made a round voyage in the air-ship from Toul, and expressed himself as highly satisfied with the same. A speed of 42 km. per hr. was attained. It is to be introduced into the French army as soon as certain improvements have been effected. Three Lebaudy air ships have been ordered for Paris, and two each for Toul, Verdun, Epinal and Belfort.

§ 11. SPAIN.

1884. 24 Dec. *Decree.*—The 4th Company of the Telegraph Battalion in Madrid was entrusted with the construction, possession, and inflating of free and captive balloons.

1889. June. The company (Capt. D. Fernando Aranguren with Lieut. D. Anselmo Sanchez Tirado) was assigned field balloon stores, ordered from Yon's of Paris, for exercising purposes.

27 June. Her Majesty, Queen Maria Christina of Spain, dedicated a military balloon, named after her, for use as a captive balloon (*I. A M.*, 1901).

19 July. First free voyage by Spanish balloon officers. (*Cf.*

1889. 19 July. *Z. f. L.*, 1889, p. 237, and D. Anselmo Sanchez Tirado, *Aerostacion Militar*, Madrid, 1889; *Z. f. L.*, 1889, p. 33.

Organisation. — Personnel in peace: 1 captain, 3 lieutenants, 10 sergeants, 17 corporals, 2 trumpeters, 4 lance-corporals, and 67 men. Also 4 officers' horses, 3 troopers' horses, 10 mules. The material was carried on 3 waggons and 10 beasts of burden.

Instruction of the company in ballooning, in telephony, and in optical telegraphy.

War personnel: 1 captain as company leader, 7 lieutenants, 28 sergeants, 42 corporals, 7 trumpeters, 14 lance-corporals, 280 men, 7 farriers. Also 8 officers' horses, 21 troopers' horses, 60 draught horses, and 30 mules for waggons.

The stores to be carried on 60 beasts of burden and 4 waggons.

1896. May. A commission, consisting of Lieut.-Col. Don José Suarez de la Vega, Chief of the Telegraph Battalion, and Capt. Don Francisco de Paula Rojas of the Telegraph Battalion, sent to study the German, French, English, and Italian systems of military ballooning.

On the report of the commission:—

30 Aug. Formation of a Balloon Company, and equipment of balloon stores (Parque Aerostático) in Guadalajara in connection with arrangements for military carrier-pigeon post service, military photography, regimental siege stores, and archives of the engineering troops, etc., at a central establishment.

Personnel of the section: 1 major (Don Pedro Vives y Vich), 1 captain (Gimenez), 2 lieutenants (Ortega and Peña), 2 non-coms., 5 corporals, and 57 men.

1898. Increase of the personnel by 1 captain (Rojas), 1 lieutenant (Kindelan), and 1 non-com.

Provision of a house in Guadalajara; exercise-place on the road to Madrid, 2 kilometres from the barracks.

1899. Major Don Pedro Vives y Vich and Capt. Zegura sent to Germany, Italy, Austria, and Switzerland to study ballooning.

1900. Introduction of the kite-balloon (805 cb. m.) and field-balloon stores, with gas waggons for 20 cylinders; gas compressed under 150 atm. pressure.

1901. 31 Dec. *Ministerial edict.*—The balloon stores placed under Captain F. de P. Rojas.

1902. 14 Jan. *Ministerial edict.*—New organisation of the Balloon Company.

1902. 14 Jan. Personnel: 1 major, 2 captains (F. Gimenez and Nava), 4 first lieutenants (Gordignela, Maldonado. Rodrignez, E. Gimenez) and 1 lieutenant (Davila); 7 non-coms., 14 corporals, 2 trumpeters, 77 soldiers; 7 officers' horses, 30 mules; 8 gas waggons, 1 luggage cart, 1 search-light waggon with a projector 90 cm. in diameter, and 1 transport waggon.

20 Sept. *Ministerial edict.*—Lieut.-Col. Vives y Vich appointed Chief of the Balloon Stores and the Balloon Companies.

28 Oct. *Ministerial edict.*—Major Isidro Calvo appointed Commander of the Balloon Company.

1905. Capt. Franrisco de Paula Rojas appointed Commandant of the Balloon Companies.

§ 12. RUSSIA.

1812/16 Experiments with a model, and building of an air-ship by the Stuttgart mechanic, Leppich, near Woronzowo, at Alopeus and Count Rumianzoff's suggestion (Frhr. v. Hagen, *Z. f. L.*, 1882, p. 354. *Cf.* Chapter XII., § 2).

1869–1874. Appointment of a commission on military ballooning under Gen v. Todleben. Experiments. (*Ing. Journ.*, 1876, Nos. 5 and 6.)

1884. 2/14 Aug. Experiments with a signalling balloon by the naval administration. Preparation and inflating carried out by the Servian ship's captain, Kostovitz, on the Werft at Ochta.

5/17 Aug. Nightly experiments with the signalling balloon on board the mine-boat *Wsriw* (St Petersburg, *Wiedomosti*, *Herold*, 2/14 August 1884).

Sept. Commission appointed by the Minister of War to carry out experiments on ballooning. President, Gen. Boreskoff, Commander of the Electrical Division of the Engineering Corps. Formation of a Balloon Division—1 officer (Garde-Sappeur Lieut. Kowanko) and 22 men.

1885. Increase of the detachment by 3 officers; transference to Wolkowo-Polje; captive balloon ascents on 23 April/5 May and the 8/20 September with 2 balloons bought from Brissonet's, of Paris (1000 and 1100 cb. m.).

Ascent of the Minister of War, General Wannowski. During the absence of Gen. Boreskoff, in Paris, for the purpose of purchasing material, Gen. Fedorow presided over the Commission.

6/18 Oct. First free voyage (Lieuts. Kowanko and Trofimow).

1886. Arrival of 2 balloon stores (Yon's system) from Paris (balloon, 640 cb. m.; *cf.* § 9). Increase of personnel by 4 officers and 32 men. Formation of 2 detachments

1886. (Lieut. Golachow and Lieut. Trofimow) for the manœuvres at Brest and Bialystock. Good results obtained at the latter, in spite of very faulty material. Participation in the manœuvres 21 August/2 September; free voyage (Gen. Orlow, Lieut. Trofimow). The firm of Yon, in Paris, were instructed to build an air-ship on their own system.

1887. Increase of personnel by 4 officers and 60 men. Experiments. Participation in the camp practices at Krassnoje-Sselo and Ust-Ishora. Free voyage 6/18 July. A commission—members, Gen. Fedorow, Col. Jasnietzki, and Capt. Welitzchko—sent to Paris to take over the Yon's air-ship. The faulty condition of the machine prevented any trials being carried out with it; the steering arrangements were useless, and the air-ship was rejected.

Provisional arrangement for ballooning schools for officers and men. Officers from forts and engineering regiments ordered to attend. Purchase of a balloon (Lachambre's system) in Paris.

1888. Continuation of the trials; frequent (9) free voyages.

1889. Experiments with a hot-air balloon (Godard's system)
6/18 June. in Brussels (3100 cb. m. inflated in ¾ hour. *Z. f. L.*, 1890, p. 289).

1890. The organisation of the balloon service was completed by the edict of 14/26 May (*Z. f. L.*, 1892, p. 132). The Balloon Division was placed under the commander of the Engineer Corps Division, and divided into—

1. *Instruction-division* under the commander of the Electro-technical Division, for the instruction of the staff, completion and care of balloon stores, and the undertaking of experiments.

In a mobilisation it forms the basis of a mobile formation.

Permanent staff in peace: 1 colonel, 2 captains, 1 staff captain, 2 lieutenants, 88 men, 4 horses. Permanent staff in war: 14 officers, 1 clerk, 215 men, 4 horses.

From 1/13 December to 1/13 October, a ten-months' course for 8 lieutenants of the Engineering Corps and the fort troops was held.

2. *Fort Balloon Division.*—Formed in Warsaw in 1891. Personnel in peace—1 captain, 2 lieutenants, 52 men; in war—1 captain, 4 lieutenants, 136 men, divided into three detachments.

Stores.—6 captive balloons (640 cb. m.), 3 free balloons (1000 cb. m.), 3 gas bags (250 cb. m.), 1 steam and 2 hand winches, apparatus for the production of hydrogen. For the latter, Garoutte's method was temporarily in use.

1890. Garoutte's apparatus consists of 4 generators each weighing 295 kg., a mixing vessel, a cooler, a dryer, and numerous sulphuric acid tuns mounted on cars. The latter were made of copper lined with lead, and held 40 pud (=655 kg.) of acid each. 1½ hours only are necessary to unload the apparatus from the cars, to put it together, and commence operations. 640 cb. m. of gas can be prepared in 2½ to 3 hours. Long train. The first echelon has 7 sulphuric acid cars. (S. Orlow, *Über die Taktik des Luftballons.* St Petersburg, 1892.)

Aug. Participation of an improvised balloon division in the manœuvres near Narwa. A balloon of 640 cb. m. was filled in 3 hrs. 5 mins. At the end of this year over 40 free voyages had been made since 1885, the results of which have been carefully tabulated by Col. Pomortzeff, and scientifically worked out. (S. Pomortzeff, *Résultats scientifiques de* 40 *Ascens.* St Petersburg, 1892.)

1891. Participation in the manœuvres near Nowo Georgijewsk. Free voyage out of the fort. The balloon "Moskau" travelled 4 or 5 hours in the direction of Brest-Litewski.

1892. June. Formation of a second Fort Balloon Division in Ossowetz. (*Russ. Inv.*, No. 218.)

An aluminium air-ship built by D. Schwarz (Austria) (*cf.* Chapter XII., § 2).

1893. July. Formation of fort balloon divisions in Nowo Georgijewsk and Iwangorod. (*Russ. Inv.*, No. 100.)

1894. Exercises in Wolkowo Polje and in Krassnoje-Sselo. Formation of a division to assist in the search for the war-ship *Russalka*, sunk in the Finnish Sea between Helsingfors and Reval. The balloon was sent up 400 m. from the ship *Samojed.* The experiment was not successful owing to the opacity of the water, but it proved the utility of balloons for the navy. Capt. Semkowski stated the results as follows:—

1. The bed of the sea, when of great depth, cannot be seen from a balloon 430 m. high.

2. Stones, beams, etc. were visible, in suitable illumination, at a depth of 6 to 8 m. under water.

3. Large sand-banks down to a depth of 13 m. were visible from a distance, owing to the colour of the water. Bodies lying on them were not distinguishable.

4. The balloon, anchored on the deck of the ship, could be towed against a wind of 7–8 m. per second at a speed of 6–7 knots, with difficulty.

5. The horizon, viewed from the balloon, is very extensive.

1894. 6. The captive balloon is steadier on the ship than on the mainland; the ship mitigates the influence of the wind to a certain extent.

7. The balloon is of value for hydrographical purposes, and will be of use in time of war to explore distant waters.

Improvement of Stores. Free voyages carried out simultaneously with those carried out from Berlin for scientific purposes.

1896. 14 Jan. Formation of a Fort Balloon Division in Kowno. (*Russ. Inv.*, No. 222, 1895.)

1896. Experiments with kites, lifting observers, and photographic apparatus. (*I. A. M.*, 1899, 1.)

1898. Lieut. Uljanin exhibited his team of kites before the Tenth Congress of Russian Physicians and Scientists, and raised men with them to a height of 200 m.

1899. Formation of a Fort Balloon Division at Jablonü, near Warsaw. The divisions of this type are well organised according to Russian ideas, although the organisation is not a fixed one. (*Cf.* W. Aiy and A. Kowanko, *Luftschiffahrt.* Cronstadt, 1900.)

1902. Experimental trial of an improvised Field Balloon Division, consisting of 3 echelons. The balloon was inflated during the march, owing to the tremendous length of time the inflation took with the Garoutte apparatus, but this greatly retarded the march. Kite experimemts in the navy.

1904. July. A Naval Balloon Division sent out to Vladivostock, and a Balloon Company to the seat of war in Manchuria. Officers: Capt. Pogulia, and Lieuts. Podobiäd, Olerinsky, and Mez. The Company took part in the battle of Liaoyan.

New stores provided for the expedition. Preparation of hydrogen by the action of aluminium on caustic soda.

Aug. Formation of an East Siberian Balloon Battalion of two companies. Mobilisation in Warsaw. Commander: Col. Kowanko. Officers: Lieut.-Cols. Wolkow and Naidenow, Adjutant Wegener. 1st Company—Capt. Nowitzki; 2nd Company—Capt. Count Baratow, First Lieut. Osbrobischin. The staff of the Battalion, on a war footing, comprised 11 officers, 618 non-coms. and rank and file; 16 riding horses, 271 pack horses and waggon horses.

4 Sept. The Battalion left Warsaw for the seat of war, arriving at Harbin in October.

5 Jan. Two companies were attached to the 2nd and 3rd Armies, while the company which had already seen action was attached to the 1st Army. The 2nd

1904. 5 Jan. Company was under fire in the battle of Mukden, on 10th January, and proved very useful to the army.

Introduction of the Sigsfeld-Parseval kite-balloon and a new balloon winch, driven by a 24 H.P. benzene motor. (*Cf.* Moedebeck, "Die russische Militärluftschiffahrt," *Illustrierte Aëronautische Mitteilungen*, p. 205, 1905.)

§ 13. THE BALKAN STATES.

1888. **Servia.**—Several signalling balloons procured. Kostowitz's system.

1889. **Bulgaria** possessed no balloon stores. In spite of this, 2 officers (Lieuts. Zlataroff and Kantscheff) and several men assisted in the ascent of the aeronaut, Eugène Godard, in the Exhibition at Philippopel, acting under the command of the Minister for War. (*Cf.* Eugène Godard, *Vingt-cinq Ascensions en Orient.* Paris, 1893.)

1893. **Romania.**—3 officers sent to Paris to be instructed by Louis Godard. Balloon stores (2 balloons) also procured, and a Balloon Section formed (1 officer, 20 men), attached to the 1st Regiment of Engineers in Bucharest. The material was stored in a specially built shed.

1902. An officer (Lieut. Assaky) sent to A. Riedinger in Germany and to Austria to study Parseval-Sigfeld's kite-balloon. The organisation of a Balloon Division with German and Austrian material is being arranged for.

§ 14. UNITED STATES OF NORTH AMERICA.

1861. Mr T. S. C. Lowe offered his services to President Lincoln during the Civil War. Trials in Washington.

18 June. First telegram from a captive balloon sent to President Lincoln at the White House.

The ballooning was placed under the direction of the Topographical Engineers.

24 July. After the defeat near Manasses, Lowe made a free voyage, and discovered in the course of it the position of the victorious Confederates, and showed the falseness of the report of their forward advance. Organisation of the Balloon Corps: 1 principal aeronaut (Mr Lowe), 1 captain, 50 officers and men. The stores consisted of 2 gas generators each for 4 horses, 2 balloon waggons (with accessories) each for 4 horses, 1 acid car for 2 horses.

1862. The Balloon Division was attached to General MacClellan's army. Reconnoitring before Yorktown.

1862. The ascent and descent of the balloon were made under heavy artillery fire. On 3rd May 1862, an ascent by General Fitzjohn Porter was rendered impossible by the heavy artillery firing. On the following day (4th May), a reconnoitring trip in the balloon showed that the Confederate General Magruder had abandoned his position in the night-time.

22 May. On account of the keen desire of the officers to take part in the captive ascents, Gen. MacClellan stated that only officers to whom he had given permission would be allowed to make ascents.

24 May. Gen. Stonemann ascended with Lowe and discovered the position of some of the enemy who were hidden near New Bridge. The artillery fire was directed against them at his commands from the balloon.

The first case of the command of artillery fire against a concealed enemy from a balloon.

27 May. Lowe ascended near Mechanicsville, in the neighbourhood of Richmond, and was fired at by three batteries of the enemy.

29 May. Gen. MacClellan discovered the purpose of the enemy, near Chikahoming, from observations taken in the balloon, and sent his reserves to the assistance of a wing of Gen. Heintzelmann's army, which was hard pressed.

31 May and 1 June. **Fair Oaks.**—Lowe telegraphed continuously to Gen. MacClellan concerning the movements of the Confederates under Gen. Johnson, and enabled him to see through the latter's plans.

June. Before Richmond the balloon was continuously employed to discover the movements of the Confederates, and to defeat their plans by suitable counter-movements. (27/6, Gaines Mills.) On the 27th June the Confederates sent up a balloon in Richmond to discover the position of the Union army. The balloon was inflated in the town, and fastened to a locomotive which could move it from place to place. Captive ascents were also made from a steamship on the James River.

Aug. Discovery by the balloon observers of the fleet under Commodore Wilkes on the James River.

The activity of the balloon corps diminished with the recall of MacClellan. The last fruitful ascent was at the attack on Mary's Heights by Sedgwick, where Lowe pointed out the weakest point of the fortifications. Lowe retired from the service of the army owing to his salary being reduced from 10 dollars to 6 dollars per day. (*Cf.* Hatton Turner, *Astra Castra*; Moedebeck, *Handbuch*

der Luftschiffahrt, p. 170; *Aeronautics*, xii., 1893; Gen. A. W. Greely, *Balloons in War*, 1900.)

1892. Formation of balloon stores on the recommendation of the Commander of the Signal Corps, Gen. Greely.

1893. A gold-beater's skin balloon (Gen. Myer) was shown at the World's Fair in Chicago, Cardani's system of suspending the car (as modified by Hervé) being used.

Transference of the stores to Fort Riley (Kan.). Instruction of the Signal Corps School in aeronautics (Lieut. J. E. Maxfield).

1894. The ballooning stores were brought to Fort Logan (Col.) and placed under Captain W. A. Glassford. A silk balloon (8000 cb. ft.) was built. Balloon stores on the English plan were procured. A balloon shed was built. (*Cf. Annual Report of Capt. W. A. Glassford, Signal Officer.* 30/6/'97.)

The balloon stores comprised 1 winch (worked by hand), corresponding balloon waggon, 5 gas waggons with 180 gas cylinders, 1 gas generator, 1 transportable gas compressor, 1 provision waggon.

The section of the Signal Corps instructed in aeronautics comprised 50 non-commissioned officers and men.

1897. Kite experiments by Lieut. Wise, of the 9th Inf. Regt., in Governor's Island (New York). He ascended 40 feet with the help of 4 Hargrave kites.

1898. **Spanish-American War.**—Mobilisation of the Balloon Division in Tampa (Flor.). It was proposed at first to form 2 divisions, each to be provided with 2 balloons, 1 gas generator, 160 gas cylinders, and the requisite means of transport, for the transference of the materials necessary for the preparation of the gas.

Major Maxfield had to proceed to Cuba with General Shafter, before the completion of this organisation, with what materials and staff he could procure in haste; he landed on 28th June in Daiquiri, and transported the material on 7 army waggons to headquarters, arriving there on 29th June.

30 June. Ascents before Santiago de Cuba.

Discovery of the Spanish fortifications. First certain confirmation that Admiral Cervera's fleet lay in the harbour.

1 July. **Near El Poso.**—Discovery of the positions on the San Juan Hill; ascent made 600 m. in front of the Spanish shooting trenches. The Spanish cavalry succeeded, under the protection of the bush, in advancing to within

1898. 1 July. 50 m. and shooting the balloon down. (*Cf. Report of the Chief Signal Officer to the Secretary of War*, 30th July 1898; and *I. A. M.*, 1899.)

After the conclusion of the war a German kite-balloon was procured (800 cb. m.).

1902–6. The War Department show great interest in the development of the dynamic flying machine, and have to this end assisted Professor Langley in the experiments with his flying machine at Washington with considerable sums of money.

§ 15. JAPAN.

1869. During the siege of the Duke v. Aidzu's fort at Wakamatzu by the Imperial troops, at the time of the overthrow of the Siogun's dominion, the besieged sent up a kite lifting a man, who discovered in this way the position of the Imperial army.

It is said that the man once ascended thus, carrying explosives, which he threw at the enemy, but without result.

1876. During the campaign near the Kumamoto fort, especially near Tawarasaka (Tabarasaka), small captive balloons were prepared by the relieving army, which were to be sent up behind the line of the besiegers to discover their position. The besiegers raised the siege and drew off to Suden as the first balloon which was ready was on the way to Kumamoto.

1886. H.R.H. Prince Komatzu ascended in a balloon belonging to the German Balloon Division in Berlin.

1890. A captive balloon (370 cb. m.) ordered from Yon of Paris. Height of ascent, 400 m. Various ascents after delivery in Japan.

The varnished silk became sticky after some years, and the envelope could no longer be straightened out.

The Imperial Japanese Artillery Division constructed a new small balloon of Japanese material.

1898. Aug. A division of the Engineers made various experiments with different balloon materials and balloons.

1899. Dec. Discovery of a special varnish (by the Research Division) which is insensitive to heat and cold. Trial experiments against heat were made in Taiwan, and against cold at Kamikawa in Hokkaido.

Various models of balloons were constructed, and the ones considered good on the small scale were constructed and tested on a larger scale. Among these a form of balloon suggested by Captain Tokunago,

1899. Dec. which was a captive balloon tapered to points at both ends, was found to give good results, and was therefore constructed on a large scale. This balloon should be of use in modern warfare, although the methods of suspension and inflation leave much to be desired.

1904. Formation of a Balloon Division (Major Tokunaga), which was sent to Port Arthur, provided with a Japanese kite-balloon (440 cb. m.), and played a prominent part during the siege. (*Cf. I. A. M.*, 1905; C. v. G., *Japan. militarische Luftschiffahrt während der Belagerung von Port Arthur.*)

1905. Introduction of the Parseval-Sigsfeld kite-balloon and the German balloon-train (Riedinger).

§ 16. CHINA.

1886. The Chinese Government ordered 2 balloons (500 cb. m. and 3000 cb. m.) from Yon of Paris.

1887. 15–17 June. These balloons were tested and forwarded by the aeronaut, Panis, to Tientsin in China (*cf. La Nature*, No. 713). The balloons did not arrive in good condition, the varnish having become very sticky under the action of the heat on the voyage. A shed was next built, of mats, for the storage of the materials, also an elegant pavilion from which the Vice-Emperor might witness the ascent.

Oct. The first ascent was only possible four months after the arrival of the balloons. The balloons were afterwards deflated and handed over to the care of the Chinese military authorities, who made no further ascents, since the material was quite unfit for use after being stored in the shed. In addition, the gas generator was badly damaged. In spite of these facts, new material was shortly afterwards ordered from the same firm.

1900. At the capture of Tientsin by the combined armies the Chinese balloon stores fell into the hands of the Russians (*I. A. M.*, 1902, p. 5).

§ 17. MOROCCO.

1902. Purchase of balloon stores from Sourcouf's successors in Paris.

Material.—Steam winch of a new pattern by Schneider & Co., Creusot; balloon of varnished silk (650 cb. m.), with air *ballonet*; 600 m. cable. Hervé's system of suspending the car (*cf.* Chapter IV., § 24, fig. 35).

B. MILITARY APPLICATIONS OF BALLOONS.

§ 1. CAPTIVE BALLOONS.

1. To discover the strength and advance of the enemy on land and in naval warfare, to explore navigable waters, to discover the approach of ships, the harbours and the torpedo batteries, using also photography and wireless telegraphy. Discovery of approaching submarine boats.

2. For observations on the development and course of the battle (in forts, positions, and naval battles, with the use of photography and wireless telegraphy), and to direct the fire of the artillery.

3. To deceive the enemy as to the positions occupied by the main body (Tonkins, *R. de l'A.*, 1890).

4. For optical signalling over great distances, especially at night, but only when wireless telegraphy cannot be employed.

§ 2. FREE BALLOONS.

1. For the discovery of large fortifications and enclosed positions by passing over them (using photography and wireless telegraphy). In naval warfare, on the high seas, to search for the arrival of the enemy from great distances.

2. For the transport of persons, carrier-pigeons, and postal matter out of besieged cities.

3. For throwing explosive bodies and fire missiles on to the enemy.

Resolution of the Peace Conference at La Hague, 1898:—

"The Powers agree, for a period of five years, to prohibit the throwing of bombs or explosive materials from air-balloons, or using analogous means" (*cf. I. A. M.*, 1900). This time has now expired.

§ 3. PILOT BALLOONS.

(*a*) **Captive** :—

1. For signalling over long distances by night.

2. For finding the direction of the wind in the higher atmosphere before sending up larger captive balloons.

(*b*) **Free** :—

3. For finding the direction of the wind in the higher atmosphere before sending away free balloons.

4. For the transmission of news, proclamations, and postal matter from besieged cities. (Metz, Belfort, Paris, 1870/71.)

5. As balloon torpedoes, in combination with explosive bodies, for dropping the latter over the enemy's positions (Venice, 1849). Very uncertain unless accompanied by free balloons, or, still better, air-ships.

Literature.—Moedebeck, *Handbuch der Luftschiffahrt*, Leipzig, 1885; Brug, *Die Luftschiffahrt und ihre Verwendung im Kriege*, Munich, 1887; Steenackers, *Les Télégraphes et les Postes pendant la guerre de 1870/71*, Paris, 1883; Hoernes, *Über Fesselballon-Stationen und deren Ersatz im Land- und Seekriege*, Vienna, 1892; Dibos, *Les aérostats dans leur utilisation militaire*, Paris, 1893; Orlow, *Die Taktik des Luftballons*, St Petersburg, 1892; *Exerzier-Règlement für Luftschiffer v. 8/10/'03*, Berlin, 1903, Part IV.

C. FIRING AT BALLOONS.

§ 1. FIRING BY MEANS OF HAND WEAPONS.

1. **Projectiles.**—The shot directed vertically upwards ascends to the greatest height. With rifles, given an initial velocity of 500 to 600 m/sec., the greatest height theoretically attainable is 12,500 to 18,000 m., the resistance of the air being left out of consideration.

It is possible to strike a balloon 400 m. high from a distance of 1500 m. The nearer the balloon approaches the fire the greater are the limits of its zone of danger, being greatest perpendicularly over the firer.

After a knowledge of the mechanical power of the weapon, the chief difficulty is its use to reach the object. If the distance is determined as accurately as possible with a range-finder, the shooting does not differ from any other, as long as the angle (angle of sight) made by the line joining the balloon to the observer with the horizon does not exceed 40°. At greater angles the sight no longer gives the true distance, and must be smaller and smaller the greater the angle. At 90°, all distances will be shot at with the standing sight.

2. **Procedure in firing.**—Dufaux, who has gone into the question thoroughly in his book, *Tir contre les Ballons* (Paris, 1886), gives the following practical rules for the Gras rifle M/74.

Elevation from 90° to 80°.		Sight 200 m.
,, 80° to 70°.		,, 200 m. sufficient to a distance of 500 m.
		,, 300 m. ,, to a distance of 800 m.
,, 70° to 60°	Two Sights	(1) Equal $\frac{1}{2}$ the estimated distance. (2) 100 m. farther than (1).
,, 60° to 50°	Two Sights	(1) Equal $\frac{2}{3}$ the estimated distance. (2) 50 to 100 m. farther than (1).
,, 50° to 40°	Two Sights	(1) Equal $\frac{4}{5}$ the estimated distance. (2) 50 m. farther than (1).

The angle of sight may be determined with a simple paper quadrant, or, after a little practice, estimated by eye.

3. **Action.**—A captive balloon will seldom approach so near that it can be shot at with rifles, though occasionally, when it comes within the range mentioned in (1), it can be shot down with the expenditure of much ammunition.

A free balloon can easily avoid the fire. This must therefore be directed against the passengers, and only when observation shows that the latter may probably be hit must the balloon be fired at. Pilot balloons, which are within range, can easily be shot down.

Shot that grazes causes the greatest damage to the envelope of the balloon.

§ 2. FIRING WITH CANNONS.

1. **General.**—The cannon becomes of use in shooting down balloons as soon as the distance becomes too great for the use of rifles. Cannon may be used with effect up to a distance of 8000 m. in warfare on land. Those firing shrapnel-shot are most effective. Explosive bombs with fuses may also be employed.

On account of the large angle of elevation at short distances, the gun-carriage must allow a sufficient elevation of the gun. The greater the distance the smaller will be the angle of elevation. For a balloon 2000 m. high, at a distance of 7000 m. it is 16°; at 8000 m., 14°. The greater distance also requires less traversing in order to follow the balloon with directed shots. The dispersion of the shell on exploding increases also with the distance, since the remaining velocity of the whole shot will be smaller, and consequently the force tending to spread out the shell will have a greater influence on the movements of the separate particles. This tends to simplify the shooting of balloons at great distances. The assumption that the firing is rendered more difficult by a to-and-fro motion of the balloon is an erroneous one.

The direction may be found conveniently with a range-finder suitably graduated.

Cannon cannot be employed effectively to fire at balloons at short distances away—the action is too slow, and the movement of the object cannot be followed quickly enough. Krupp experimented, in 1870, to get over this difficulty by the construction of a balloon cannon. It failed, however, to serve any useful purpose, and the poor results attained with the cannon must be attributed to this difficulty. (See also *Règlement sur le service des bouches à feu de siège et de place.* Paris, 1893, p. 16.)

2. **Shooting methods.**—As a rule, the firing is carried out by batteries of from 4 to 6 cannon. The methods used may be found in the articles given below. (See *Exerzier-Reglt., der Feld-Artillerie ; Schiessanleitung für die Fuss-Artillerie*, p. 49 ; v. Seydlitz, *Die Shiessregeln der russischen Feld-Artillerie im Jahre 1891*, Dresden, 1892, p. 25 ; *Shiessregeln der Festungs und Belagerungs-Art in Russland*, published under the direction of the Artillerie-Hauptverwaltung, 1900 ; *Mitteilungen über Gegenstände der Artillerie- und Genie-Wesens*, 1901, vol. i. ; Vallier, "Tir contre les Ballons," *Revue d'Artillerie*, xxx. 15/4/'87 ; *R. de l'A.*, 1890 ; *I. A. M.*, 1901, p. 57.)

3. **Action.**—Captive balloons will be readily shot down as soon as their distance is accurately known. Their height and movements scarcely increase appreciably the difficulty of shooting. Near the balloon, explosive shells and burning fuses set it on fire.

Shot or pieces of shell striking the balloon cause it to lose gas and sink more or less slowly.

Free or pilot balloons are more difficult to shoot with field artillery, and can only be followed at considerable distances and not too great heights.

D. THE MILITARY AIR-SHIP.

Although the military air-ship, even the Lebaudy air-ship, has not yet been brought to a state of perfection, and the following statements are consequently based on suppositions, yet it may nevertheless be not premature to set forth some considerations concerning the ideal of military air-ship travelling.

The utility is dependent on the mechanical power of the vessel. For this the following must be taken into account: independent velocity, possible length of voyage, carrying power, light power-generating material lasting for a long time, skilled personnel.

§ 1. RECONNOITRING.

Air-ships should be of use, before the commencement of hostilities, for investigating the approach of the enemy and the strength of his army, and the state as regards armament of the enemy's outposts, so far as can be observed from the frontier.

If the frontier can be crossed, the above problems may be solved much more completely. The greater the radius of action of the air-ship is, the more useful it will prove. It must be remembered that, with the prevailing west winds of our latitude, development against the west will be most favourable; if the air-ship is damaged, the chances of its being carried homewards by the wind are better. The strategical value of the air-ship must be considered in connection with Marconi telegraphy, with which the Cavalry Divisions in the field must also be equipped.

The efficacy of the military air-ship as a means of obtaining information will, for the present, cause this to remain its chief sphere of activity.

§ 2. THE MILITARY AIR-SHIP AS WEAPON.

The increasing difficulty of directing artillery fire at an enemy who is in position at great distance away is one of the problems which will be solved by the development of the military air-ship.

In a manner analogous to the action of the torpedo in naval warfare, the heavy artillery of the field army will be reinforced as regards destructive power by air-torpedoes directed from the air-ship.

A war waged in this manner will be more humane than one as at present conducted, since in this case only the destruction of the means of resistance of the enemy will be aimed at; whereas in shooting over long distances useless destruction of another nature is wrought, and is indeed quite unavoidable (*e.g.* Destruction of the library and theatre during the siege of Strassburg i. E., 1870/71).

The means of destruction to be cast from the air-ship will include the strongest explosive bomb materials and poisonous gases, which will render the positions in the regions under fire untenable by man, and render the food and forage which is affected unusable. Against other air-ships and balloons quite light flares can be made use of, designed to act only after they have been thrown.

The transport of such fighting material, technically considered

from an aeronautical standpoint, is only possible in very small quantities.

The following points must be borne in mind in designing a military air-ship:—

(*a*) It must be able to travel at such a height that it is as safe as possible from rifle fire.

(*b*) It must be able to cast out such a quantity of ammunition that the object of the fight may be accomplished.

(*c*) It must carry, in addition, a quantity of ballast sufficient to ensure a safe return and landing.

The disposable ballast of a military air-ship must be divided into—"Fighting ballast" for throwing over the object; ballast for use in attaining a safety zone; manœuvring ballast for the outward and return voyage; and landing ballast.

How great a quantity of explosive material must be thrown out to cause a sufficiently damaging action can only be learned by trial (*cf.* A., § 2). When the material is thrown out, the air-ship of course ascends, and the height of ascent may be easily determined by the law governing the action of ballast.

Example.—Assuming that Renard-Kreb's air-ship (1884) or Graf von Zeppelin's air-ship (1900) throws out 100 kg. ammunition, then the height may be determined by the formula:

$$\Delta h = h_2 - h_1 = 8000 \frac{g}{G},$$

after substituting the values corresponding to the particular air-ship.

For Renard-Kreb's air-ship, $\Delta h = 8000 \times \frac{100}{1800} = 444$ m.

For Graf v. Zeppelin's air-ship, $\Delta h = 8000 \times \frac{100}{10{,}200} = 78$ m.

i.e. in this case the larger and heavier air-ship is superior to the smaller and lighter one, since its position of equilibrium as regards altitude is altered comparatively little by the loss of weight. The zone of safety against rifle fire has its lower limit at a height of 1500 m., according to the available data.

Neglecting the temperatures of the gas and air, the normal heights for the balloons are:—

Renard-Kreb's (A.V = 2000 kg.; G. = 1900 kg., including 100 kg. ammunition).

$$n = \frac{A.V}{G} = \frac{2000}{1900} = 1{\cdot}05, \text{ corresponding to a height of 390 m.}$$

(*Cf.* Table XVII.)

Graf v. Zeppelin (A.V = 11,500 kg. when 97 per cent. full; G = 10,300 kg., including 100 kg. ammunition).

$$n = \frac{A.V}{G} = \frac{11{,}500}{10{,}300} = 1{\cdot}11, \text{ corresponding to a height of 834 m.}$$

Neither vessel would therefore be in a position to escape into the zone of safety even by the use of manœuvring and landing ballast.

The air-ship will first play a part of supreme importance as a weapon, when heavy artillery is not a certain enough means of resistance against the enemy (great range and insufficient observations), or useless (as when out of range, or against the retreat of the enemy after a fierce battle, to rout them completely).

It must be remembered that even an ideal air-ship will be dependent, to some extent, on the weather, against which it will be necessary to erect some kind of a shelter.

§ 3. THROWING OUT BALLOON MISSILES.

We may assume that, if handled skilfully, the object aimed at will be hit very exactly. We must distinguish between the throw when the air-ship is at rest and that when it is in motion. In throwing out while at rest, which is only possible when the air-ship can travel against the wind, the following points must be considered:—

(*a*) The height of the object. This may be accurately determined from the contour lines on the map, or from a determination of its normal barometric height. Both must be done before starting.

(*b*) The height of the air-ship above the object. The barometric height is read and reduced to normal conditions. The difference in heights as found from (*b*) and (*a*) gives the height above the object.

(*c*) The velocity of the wind. May be read on an anemometer in the air-ship, or determined beforehand by captive balloons.

(*d*) The time of fall; given by the law of gravitation, from the determination under (*b*).

The height of fall $= h = g\frac{t^2}{2}$.

Whence the time of fall $t = \sqrt{\frac{2h}{g}}$.

(*e*) The resistance of the air $R = \frac{\gamma}{g} Fv^2$.

(*f*) The leeway; the longer the fall, and the lighter and larger the falling body, and the stronger is the drift.

For known missiles, the drift for different heights and wind velocities may be determined practically.

(*g*) Unsteadiness of the air-ship. The irregularity of the pressure of the wind, and its constant variation in direction, renders it impossible for the air-ship to remain perfectly steady.

The elements stated under (*b*) and (*f*) must be rapidly determined, and suitable tables have been prepared for this purpose.

The irregularity of the wind, and the peculiarities of the air-ship mentioned under (*g*), render a preliminary trial necessary. The drift also is determined by this method, before the large air-torpedo is cast out.

The air-torpedo must be brought by sight vertically over the object by steering the air-ship, the value of the mean drift previously determined being allowed for.

In throwing out a missile while actually travelling, the velocity of the air-ship must be taken into account, as well as the elements (*a*) to (*g*) given above, since this velocity is also possessed by the body thrown out.

The determination of the proper point is now greatly increased in difficulty. Its position is a function of the relative height of the air-ship above the object, of the velocity, and of the drift, and allowance must be made for all these factors. For this purpose, motion either with or against the wind is the simplest. On account of the point on the earth over which the missile must be thrown out not being in general well marked, it is necessary to use also angles of sight.

The problem before the aeronaut is, then, as follows :—For a given height, velocity, and drift to find the necessary angle of depression, at which the missile must be thrown out in order that it may fall on to the object.

The casting out of the missile against the object while travelling is governed, therefore, by the same rules as those governing the discharge of a torpedo from a torpedo boat.

If the military air-ship can carry several air-torpedoes at once, it is without doubt an advantage. It is, on the other hand, no great disadvantage if it ascends more frequently, each time taking up a new missile, and if the right position can be found each time for the discharge, and the destructive result of the missiles is as was expected. It is of the greatest importance to ensure that the carrying power is not diminished by a loss of gas, owing to the discharge of the ammunition, or at least that the vessel may be replenished with gas simultaneously with the reloading of air-torpedoes.

§ 4. AIR-SHIP AGAINST AIR-SHIP.

An enemy in the air must eventually be fought in the air itself. It is difficult at the present time to foretell how such a battle would progress. According to the practical knowledge of the build of air-ships up to the present, the following points must be agreed to :—

Striking against another air-ship, or firing at it by means of fire weapons, is equally dangerous to each side, and must therefore be left out of consideration.

It may be possible, on the other hand, to cut at the enemy's air-ship in travelling past, or from above, by means of suitable apparatus carried on the air-ship.

Further, it seems probable that, by passing above the enemy's air-ship and dropping on to it quite small ammunition exploding on contact with any surface, it might be destroyed.

Under any circumstances, the particular military air-ship capable of travelling with the greatest velocity would be able to attack with ease another having a less velocity.

Finally, combustible missiles, igniting only on striking a body, would be dangerous weapons directed against the enemy's balloon, and could perhaps be used with advantage also by a slow moving ship against a faster one if only it could attain a height sufficiently great, more rapidly than its opponent.

Balloon ammunition can, of course, only be cast out sideways or upwards by means of springs or compressed air (liquid air ?), and if the action is limited to small distances.

These means of destruction may also be used against any captive balloons which may be about.

§ 5. THE AIR-SHIP AS A MEANS OF TRANSPORT.

One may prophesy that the transport of single passengers and important letters will be carried out by air-ships more safely, and in a shorter time, than by any other means. The rate of progress will be slow, though, even if the ships are not of the highest degree of perfection, many opportunities occur by which imperfect air-ships in the hands of skilled conductors may be of the greatest use. Their value as a means of transport will be especially great on a battlefield where other modes of transport are lacking.

In consequence of the danger of attack by unfriendly air-ships,

the traffic in the air in times of war will be principally restricted to the night-time.

By its very nature the air-ship can never be utilised for the transport of very large or heavy objects.

Literature.—H. W. L. Moedebeck, *Die Luftschiffahrt, ihre Vergangen heit und ihre Zukunft, insbesondere das Luftschiff im Verkehr und im Kriege.* Strassburg i. E. K. T. Trübner, 1906.

CHAPTER X.

ANIMAL FLIGHT.

BY PROFESSOR DR KARL MÜLLENHOFF.

§ 1. LITERATURE.

EXPERIMENTS were made as early as in the 16th and 17th centuries to determine the laws governing the flight of birds. (Leonardo da Vinci wrote, in 1514, the *Codice sul volo degli uccelli*—Paris, Rouveyre, 1894; Borelli, *De motu animalium*, 1680.) These exertions were fruitless, since observations of bird movements with the naked eye are quite insufficient and often lead to faulty conclusions; and, naturally, calculations based on these incorrect foundations would also lead to unreliable and erroneous deductions. In later times Prechtl (*Untersuchungen über den Flug der Vögel*—Vienna, Gerold, 1846) and Strasser (*Über den Flug der Vögel*—Jena, Fischer, 1885) have taken many direct observations, and have sought to apply these observations, with the aid of a mathematical treatment, to the building up of a theory of flight. Pettigrew (*Encyclopædia Britannica*, ninth edition, vol. ix., "On Flight," and *Die Ortsbewegung der Tiere*—Leipzig, Brockhaus, 1875) has attempted, with just as little success, to compare the flight of birds with other forms of animal movement.

Chronological methods (Marey, *La méthode graphique*—Paris, Masson, 1884) and instantaneous photography (Eder, *Die Momentphotographie in ihrer Anwendung auf Kunst und Wissenschaft*—Halle, Knapp, 1886) have made it possible, for the first time, to follow the details of the movements, and to depict them reliably. Both methods of observation were in the first place developed by Marey and applied by him. (Marey, *La machine animale*—Paris, Baillière, 1873; also, *Le vol des oiseaux*—Paris, Masson, 1890; and *Le mouvement*—Paris, Masson, 1894.) Marey's articles are, without doubt, the most important of all publications on flight; a warning must be issued against the use of the older literature, namely that of Strasser and Pettigrew, which abounds in errors.

The principal laws of flight have been lately collected together by Ch. Labrousse, but only very superficially (*L'Aérophile*, 1893, Nos. 11–12; 1894, Nos. 1–2).

§ 2. METHODS OF FLIGHT.

We can distinguish between five methods of flight: (*a*) Rowing flight; (*b*) Gliding flight; (*c*) Soaring; (*d*) Sailing; (*e*) Circling.

The first reliable observations on rowing flight were obtained with Marey's chronograph. With this apparatus the rhythm, extent, and direction of the movements were obtained for different points of the surface. Afterwards the form of the whole was determined photographically by several series of exposures, showing the movement of the surface of the animal at every instant. Since the animal while in flight was photographed from three sides simultaneously it was possible to depict the results of the photographic exposures in relief, in order to get rid of the perspective fore-shortening, unavoidable in every method of photography. Marey's *Vol des oiseaux* should be consulted with reference to the details of rowing flight.

Gliding flight is rowing flight interrupted by passive flights—the gliding. During the gliding the flapping of the wings is abandoned, and the flight is sustained by the kinetic energy generated during the rowing flight.

During soaring, the bird remains over a point on the ground without flapping its wings; soaring is rendered possible by upward currents of air, forming over wooded land and on rugged rocks. The activity of the muscles is confined, in this case, to feeble balancing turns of the stretched wings about the long axis. (The "soaring" of many flies, *e.g.* the "syrphides," is a stationary rowing flight.)

Sailing is seen frequently with sea-gulls following ships or progressive waves This movement is caused by the wind, reflected upwards after striking the sails or crests of the waves, holding the bird at a constant height and at a constant distance away from the sail or the wave-crest, as the case may be. The difference between sailing and soaring is, that the animal not only remains at a constant height, but in the former case is also driven forwards.

The explanation of the circling of birds is attended with especially great difficulties. Circling is impossible in still air, or when the whole movement of air proceeds regularly and with the same velocity (Gerlach, *Z. f. L.*, 1886, p. 281). It has been stated to be due to the pulsations of the wind (Langley,

American Journal of Science, 1894, ser. 3, vol. xlvii. p. 41); to ascending currents of air (Lilienthal, *Der Vogelflug als Grundlage der Fliegekunst*—Berlin, Gärtner, 1889); as well as to the fact that wind velocity gradually increases with the height (Lord Rayleigh, *Nature*, vol. xxvii., p. 537). Which of these possibilities corresponds to the actual circumstances is a question which can only be decided when the slight movements of the winds during the circling, as well as the currents of air employed for it, have been accurately determined. The problem may be solved, according to Marey (*Vol des Oiseaux*, p. 20), by several observers making simultaneous chronophotographical exposures of circling birds from different positions, using at the same time ascending pilot balloons.

§ 3. CLASSIFICATION OF BIRDS ACCORDING TO THEIR METHOD OF FLIGHT AND SIZE OF WINGS.

1. The size of the wing surfaces (f) is principally of importance in rowing flight; in passive flight, *i.e.* gliding, soaring, sailing, or circling, the total area of the under-surface of the bird (F) acts as the lifting surface.

2. Animals having similar methods of flight and of different weights (p) have geometrically similar builds:

$$\frac{f}{p^{\frac{2}{3}}} = \text{const. (Prechtl).}$$

Other expressions for the same law are given by Lucy (*Presse scientifique des deux mondes*, 1865), who puts

$$s = \frac{f}{p}; \; p\, s^3 = \text{const.};$$

Harting (*Archives needlandaises*, iv., 1869), who puts

$$F^3 = p^2 \times \text{constant};$$

and Müllenhoff (*Pflügers Archiv für Physiologie*, Bonn, 1884, vol. xxx.), who puts

$$\sigma = \frac{F^{\frac{1}{2}}}{p^{\frac{1}{3}}} = \text{const.}$$

3. With animals whose sailing power $= \frac{F^{\frac{1}{2}}}{p^{\frac{1}{3}}}$ is of different magnitude, the power to glide, soar, sail, or circle with flapping the wings increases with increasing σ.

4. The following types of flight may be distinguished between according to the sailing power and the length of wing:—

(*a*) Quail type $\sigma = 3$.
(*b*) Pheasant type $\sigma = 4$. Wings short.
(*c*) Sparrow type $\sigma = 4$. Wings moderately long.
(*d*) Swallow type $\sigma = 4$. Wings long.

(*e*) Hawk type $\sigma = 5$. Wings moderately long.
(*f*) Sea-gull type $\sigma = 5$. Wings long.
(*g*) Butterfly type $\sigma = 6$ to 7.

5. The rapidity of the flapping of the wing is greater the smaller the animal; the relation between the weight of the body and the rapidity of flapping has not yet been discovered, owing to lack of data. The few measurements hitherto carried out make it probable that for similarly built birds the frequency of stroke is inversely proportional to the linear dimensions. (For 3–4, see Müllenhoff, *Die Grösse der Flugflächen*, Pflügers Archiv, 1884, Bonn.)

§ 4. POWER EXPENDED IN FLYING.

1. The quantity of muscle in a bird is about one-sixth of the weight of its body, this applying equally to large or small animals. The same relation exists approximately between the muscle culture and bodily weight for birds as for running and leaping mammals.

2. The power of the muscles of birds is not greater than that of mammals; no difference exists in the power of equal weights of muscle between large and small animals.

3. Large animals have to perform rather more work in order to raise themselves from the ground, in proportion to their weight, than small animals. Large animals have, on the contrary, an advantage over smaller ones in that, in straight flight, they have to overcome a comparatively small head resistance. The advantage and disadvantage about compensate one another. (For fuller account, see Fuchs, *Riesen und Zwerge*, Kosmos. ix., No. 2, 1885.)

4. The velocity attainable in flight by large and small animals is, speaking generally, the same. (For 1–4, see Müllenhoff, *Die Grösse der Flugarbeit*, Pflügers Archiv, 1885.)

5. Everything known with regard to muscle culture tends to show that the energy of the bird is proportional to its weight. (Marey.)

6. (*a*) The geometrical similarity between large and small animals; (*b*) the agreement of large and small animals with regard to their relative muscle culture and the power of equal masses of muscle; (*c*) the relation between weight and frequency of stroke—$p^{\frac{1}{3}} : p_1^{\frac{1}{3}} = v_1 : v$; (*d*) the equality of the velocity attainable by large and small birds; and (*e*) the proportionality between bodily weight and energy, are all explicable on the assumption that the resistance of the air is proportional to $f^{\frac{3}{2}}$, where f is the area of the surface. (Parseval, *Die Mechanik des Vogelfluges*—Bergmann, Wiesbaden, 1889, p. 116.)

CHAPTER XI.

PART I.

ARTIFICIAL FLIGHT.

By Major H. W. L. Moedebeck.

A.—HISTORICAL.

§ 1. LEGENDS AND STORIES.

The history of flight on the part of man may be traced back to the time of the sages, a proof of how constantly, through thousands of years, men have busied themselves in trying to solve the problem of artificial flight.

The legend of Daedalus and Ikarus is generally known. The ancient Teutonic myth of Wieland the smith, in the "Wilkina and Niflunga Saga," is less generally circulated.

On the command of King Nidung of North Jutland the tendons of both feet of Wieland, an inventive genius, were cut through. In order to travel about in spite of this difficulty, Wieland built himself a flying cloak for which his brother Egil provided him with the feathers. The latter had also to make the first trial with the completed apparatus. Wieland instructed his brother to fly against the wind, and gave him purposely the false advice to descend with the wind, since he feared that his brother might fly away with the cloak. In descending, therefore, Egil had a terrible fall. On the pretence of improving the apparatus, Wieland put it on himself, with the aid of his brother, and at once flew away to his fatherland. (*Altdeutsche und altnordische Heldensagen*, translated by Friedr. Heinrich v. d. Hagen, Breslau, 1855 ; *Z. f. L.*, 1893.)

Similar legends are to be found in the folklore of many races.

Narratives relating to attempted flying descents from towers and houses are not less numerous ; in most cases the results are said to have been disastrous. (Kramp, *Geschichte der Aërostatik*, Strassburg, 1784, Part II. ; G. Tissandier, *Histoire*

des Ballons, Paris, 1887 ; Chanute, *Progress in Flying Machines*, New York, 1893 ; Hatton Turner, *Astra Castra*, London, 1865 ; Frhr. vom Hagen, *Über dynamische Flugapparate*, *Z. f. L.*, 1882.) Since all these stories give next to nothing concerning the apparatus and methods used, they are quite without importance in the development of artificial flight.

§ 2. LEONARDO DA VINCI.

We find the first technical designs for an arrangement to serve for personal flight among the papers left behind by Leonardo da Vinci (1452–1519). According to the ideas of

FIG. 81.—Leonardo da Vinci's winged apparatus for flying.

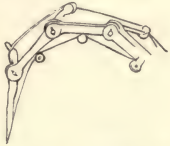


FIG. 82. — Leonardo da Vinci's linked wing.

the great master, the flying person places himself in a horizontal position and works the flying stroke with his arms,

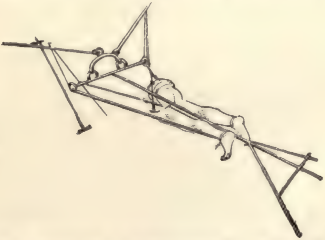


FIG. 83.—Mechanism of flying apparatus (Leonardo da Vinci).

and the descending stroke with his feet, by means of ropes passing over pulleys (fig. 81). The bat-like wings were so constructed that they consisted of several parts (fig. 82), which

flapped together with an upward stroke, whereas with a downward stroke the whole wing surface spread itself out. A tail surface was provided beneath the stretched legs (fig. 83). (*L'Aé.*, 1874 ; *The Aeronautical Annual*, 1894.)

§ 3. BESNIER.

A French locksmith, P. Besnier of Sablé (Maine), made a name for himself by his design of a peculiar apparatus for flying, differing from the model of the bird, and described in the *Journal des Scavans* of the 12th December 1678.

He laid over each shoulder a rod (fig. 84), provided at each end with collapsible right-angled aeroplanes (A B C D). With every upward movement the planes flapped together, and, with

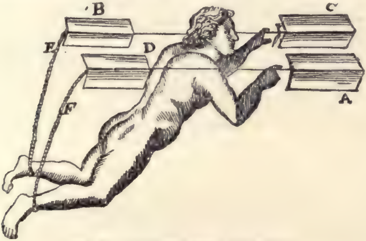


FIG. 84.—Besnier's flying apparatus.

every downward movement, formed a wide soaring surface. The two front surfaces (A and C) were moved by the arms, the hinder ones were fastened by two cords (E, F) to the legs. Besnier imagined that the alternate down-strokes of the surfaces —in front to the right, behind to the left (A and B) and in the opposite sense for C and D, about the shoulder as fulcrum— would enable flights to be made. The discoverer did not suppose that he could lift himself—only that he could fly from any lofty point in any desired direction. (G. Tissandier, *La navigation aérienne.* Paris, 1886.)

Note.—Apparatus based upon similar principles: The **Marquis de Bacqueville** altered Besnier's design by buckling on an aeroplane to each arm and leg. His experiments in Paris (1742) over the Seine miscarried.

Bourcart prepared, in 1866, two rudder wings which he laid over the shoulders and worked up and down by the foot. The leaves of the wings had an elastic edge. The experiments were without result. (O. Chanute, *Progress in Flying Machines.*)

Dandrieux improved the apparatus (1879) by introducing an elastic rudder which was worked by treadles and described a curve of the form of an 8. He was able to lighten the weight by the use of the rudder.

§ 4. J. A. BORELLI.

Until the middle of the nineteenth century, the most important work on flight was J. Alphonsi Borelli's *De motu animalium* (Rome, 1680). At the conclusion of the first scientific treatment of the flight of birds, the Neapolitan scientist stated "that it would be impossible for man to fly artificially by means of his own energy." He founded this statement on the supposition that man lacks the large muscular force in the breast, which birds possess, and that he is too heavy in comparison to the latter—especially, as in addition to his own weight, the weight of the flying apparatus must be taken into account. Borelli thought further, that it might be quite possible to lighten one's weight by the use of Archimedes' principle, and gave as an example the use of swimming bladders in fish.

"Some," said he, "are of the opinion that one could obtain a vacuous bladder, or one filled with a very light fluid, on to which a man could hang." Borelli himself, however, refused to accept the practicability of this idea, although he suggested that the bladder should be made of metal. He mentioned the size and weight of the bladder which would be necessary, and the difficulty of its manufacture.

This declaration of the impossibility of artificial flight on account of the weakness of the breast muscles remained for two hundred years one of the gospels of science, and hindered for that length of time the further development of the subject; scientists taking for granted that the bird possessed great strength relatively to man, and that this was necessary for flight.

Note.—**The further investigation of the flight of birds (*cf.* Chapter X.) has been carefully followed by all aeronauts, and it is without doubt true that the physiological works published on the subjeet by Pettigrew (*Animal Locomotion*), Marey (*Le Vol des Oiseaux*, Paris, 1890), Mouillard, and others have exercised an immense influence on it. On the other hand, many aeronauts (Karl Milla, O. Lilienthal, K. Buttenstedt) have tried to develop their theories of artificial flight from their own observations on the flight of birds.**

§ 5. K. F. MEERWEIN.

Karl Friedrich Meerwein, Inspector of Public Buildings for Baden, to whom apparently Borelli's works were unknown, published an article, "Ob der Mensch nicht auch zum Fliegen gebohren sey?" in the *Oberrheinischen Mannigfaltigkeiten*, 1782, and, two years later, brought out a book, *Die Kunst zu fliegen nach Art der Vögel.*

He was the first to experiment on the size of wing surface necessary for a man, using as a basis the weight and wing area of birds. Taking the wild duck as his model, he found that a man, weighing 200 lbs. with the machine, would require a surface of 126 sq. ft. or about 12 sq. m. This number has since been verified by the later experiments of Lilienthal. Meerwein refused to admit that the build of a man is very unsuitable for flight, for, since a man can hang quite well horizontally in the air, his feet can be used to regulate the rudder, or a rudder may be formed of the legs themselves by fastening a fabric surface between them ; and the respiration

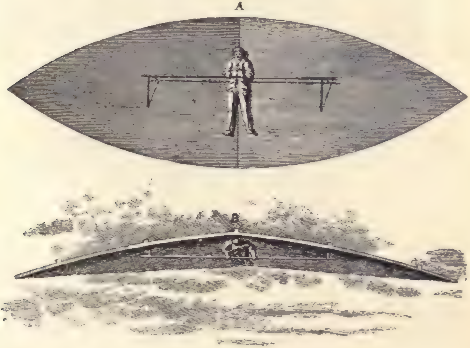


FIG. 85.—Meerwein's flying apparatus.

need not be interfered with, since the nose is so formed that when one is lying on the stomach the air opposing the motion cannot enter into the nose and lungs. Concerning the necessary power, he deceives the reader with considerations about the power of a man, and concludes in a perfectly unintelligible manner that the man hangs in the wings, and that these therefore do not come into account in considering the weight.

His apparatus (fig. 85) consisted of two light wooden frames covered with calico, which assumed the form of a spindle (A) when spread out ; this was constructed in 1781, and had an area of 111 sq. ft., weighing 56 lbs. The aviator was imagined

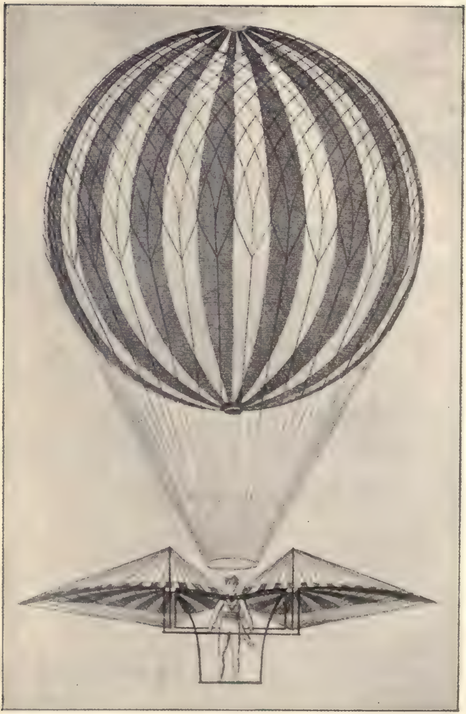


FIG. 86.—Degen's flying apparatus—elevation.

fastened in a horizontal position in the middle, with a balancing rod in front of him, which worked the strokes of the wings when pressed by the body.

For practising flight, he proposed an eminence over deep water. According to Johann Lorenz Boekmann (*Kleine Schriften physischen Inhalts*, vol. i., Carlsruhe, 1789) he made an experiment in Giessen, which was not very successful.

§ 6. J. DEGEN.

The experiments of the Viennese watchmaker, Jakob Degen, carried out in 1808 in Vienna, and in 1812 in Paris, are only worthy of mention because he balanced the weight of the flying mechanism by a counterpoise which hung over rollers on a roof (that of the Reithaus in Vienna), and, later, hung free in space by means of a small balloon, which met here with its first

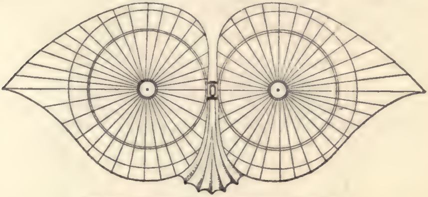


FIG. 87.—Degen's flying apparatus—plan.

application. The experiment lost, however, its aeronautical interest on account of this balloon coupling, since Degen was after this soon led to ordinary ballooning flight, the action of his wings not being recorded.

The wings were furnished with clap valves in order to decrease the resistance during the upward stroke, and had a surface of 116 sq. ft. or about 11 sq. m.

(Jakob Degen, *Beschreibung einer neuen Flugmaschine*, Vienna, 1808; Zachariae, *Geschichte der Luftschwimmkunst*, Rossleben, 1823; G. Tissandier, *La navigation aérienne*, Paris, 1886; G. Tissandier, *Histoire des Ballons*, Paris, 1887; *I. A. M.*, 1904.)

§ 7. J. BERBLINGER.

The experiments of Joseph Berblinger, a tailor of Ulm, who wished to fly down from a scaffold on the Adlerbastei by means

of wing strokes, in May 1811, on the occasion of a visit of King Friedrich of Württemberg to the town, are of still less importance. In consequence of an accident to the wings, the experiments were postponed until the following day (30th May). Berblinger fell perpendicularly downwards into the Danube.

This accident has given rise to numerous legends connected with the scene of the affair.

Note.—The primitive imitation of the flight of birds by the flapping of wings has been so often experimented on without success, that it would lead too far to recall here all details relating to the numerous cases.

It may be recalled that Fredrich Hermann Fleyder, of Tübingen, spread the idea, in a published lecture of 5th September 1617, that man could fly like a bird, if only he were trained to do so from his youth, and that he gave at the same time a programme of such exercises in flying.

Fleyder's idea has found adherents up to the present time. We refer to Frhr. v. Wechmar's *Flugtechnik* (published in 1888 and 1891), and to the experiments on flight carried out by Albert Schmutz, in Paris, as lately as 15th June 1902. The latter leaped from one of the Seine bridges, provided with wings, and was only saved with difficulty from death by drowning (*L'Aér*, July 1902; *I. A. M.*, 1902, No. 4, 1904, No. 9).

§ 8. F. VON DRIEBERG.

Friedrich von Drieberg published a pamphlet, *Das Dädaleon, eine neue Flugmaschine* (Berlin, 1845), which must receive some

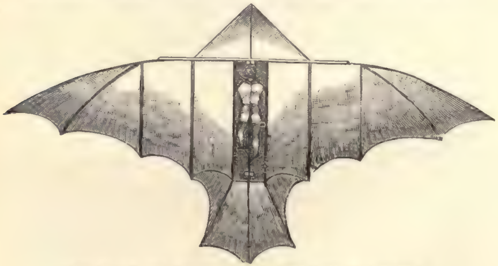


FIG. 88.—F. von Drieberg's Dädaleon (after the original).

mention, since he states that man has the greatest power in the muscles of the leg, and must use these for the movements of flight. Leonardo da Vinci had, indeed, already expressed this thought in his drawings, but his drawings were only discovered

and published for the first time towards the end of the nineteenth century; and after the appearance of Borelli's *De motu animalium*, in 1680, no one had been able to free himself from the idea that the wings must necessarily be moved with the arms.

Drieberg's proposal (fig. 88) consisted of a bat-like flying apparatus of an area of 150 sq. ft. or about 14 sq. m., in which flight was caused by working the wing strokes by treading with the feet, while lying horizontally.

§ 9. F. H. WENHAM.

A most important advance in the progress of aeronautics was brought about by Francis Herbert Wenham, who came to the conclusion, after studying the model of a bird, that the lifting

FIG. 89.—Framework of Wenham's flying apparatus.

power of a large carrying surface may be attained by arranging a number of small surfaces above each other in tiers. The large surfaces necessary for flight, said Wenham, are too difficult for a man to control, since they must be 18 m. long and 1·2 m. broad (21·9 sq. m.) in order to carry him. Besides this, the framework necessary becomes too heavy.

Wenham built a rigid framework of thin planks and bands of

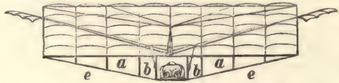


FIG. 90.—Wenham's flying apparatus (from the rear).

iron (fig. 89, *a a*, *b*, *d d*, *c c*) with six thin holland surfaces lying above one another, each 4·87 m. long and 38 cm. wide. As he placed himself in a strong wind with his head and shoulders in the triangle *b*, and attempted to hold the apparatus against the wind, he was lifted up and thrown backwards.

He proceeded after this to build a flying machine (figs. 90, 91, 92), in which the aviator places himself in a horizontal position in a framework of wood (fig. 90, *a*, *b*; fig. 91, *f*) and steel tie bands (fig. 90, *e*, *l*), supporting above six webs of thin holland each 4·87 m. long and 38 cm. wide. These six aero-

planes are kept in parallel planes by vertical divisions of holland 0·6 m. wide.

At the front two winged rudder propellers were provided. The latter were held aloft by a light spring, and could be powerfully worked by the legs of the aviator by means of a

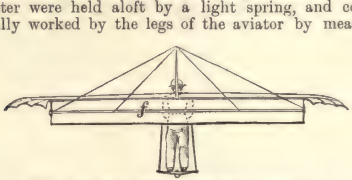


FIG. 91.—Plan of Wenham's flying apparatus.

string passing over pulleys. If one leg was stretched out more than the other, the paddle propeller was struck down farther on the corresponding side. In this manner, Wenham hoped to effect turning operations with his flying machine.

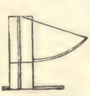


FIG. 92. — Side elevation of Wenham's flying apparatus.

Wenham made several experiments which gave him valuable results relating to the driving power of his arrangement of surfaces, without, however, being able actually to fly with it.

("Aerial Locomotion"—from the *Transactions of the Aeronautical Society of Great Britain*, London and New York, 1867, p. 10. Wenham's patent, No. 1571; 1866, 7th June.)

§ 10. H. VON HELMHOLTZ.

As a member of a commission called by the State to decide certain aeronautical questions in the year 1872, Helmholtz summarised the results of his investigations on the flight of man in a work entitled *Ueber ein Theorem geometrisch ähnliche Bewegungen flüssiger Körper betreffend nebst Anwendung auf das Problem Luftballons zu lenken* (Monatsschrift der Kgl. Preussischen Akademie der Wissenschaft zu Berlin. June, 1873).

He knew that with an increasing size of the flying body the work required for soaring increased in a much greater ratio than the volume of the body, and, therefore, than the muscles which must exert the power. He thought, therefore, that it must be assumed that the size of a bird has an upper limit, which had probably been reached in nature in the case of the large hawk.

Concerning human flight, he concludes as follows:—

"Under these circumstances it can scarcely be considered

probable that man, even with the help of the most ingenious wing-like mechanism, depending on his own muscular force as the driving power, will be placed in a position to be able to raise his own weight in the air, and to retain it there."

§ 11. O. LILIENTHAL AND G. LILIENTHAL.

After this damaging critique of all the experiments on flight hitherto carried out, further investigations on similar lines were suspended until Otto Lilienthal published the results obtained by him, working in conjunction with his brother, after long years of quiet scientific study and experiment, in the epoch-making work, *Der Vogelflug als Grundlage der Fliegekunst, ein Beitrag zur Systematik der Flugtechnik* (Berlin, 1889). This book contained the discovery of the driving forward of arched surfaces against the wind. A new genius revived now, all at once, the thought of human flight, which had become a subject to be scoffed at owing to the numerous mishaps which had hitherto occurred.

Otto Lilienthal (born at Anklam, 24th May 1848 ; died at Berlin, 10th August 1896) showed that one must begin with the "sailing" flight, and that first of all the art of balancing in the wind must be learned by practical experiments. From gradually increasing starting heights he made innumerable personal flying experiments. From a height of 30 m. he glided over distances of 200 to 300 m. in sailing flight, without any exertion, and he succeeded in deviating his direction of flight to the right or left merely by altering the position of his centre of gravity by a corresponding movement of his legs, which were dangling freely from the seat.

After Lilienthal had attained sufficient certainty in sailing flight, he proposed to apply himself gradually to rowing flight. For this purpose he constructed a light motor of 2½ H.P. and weighing 40 kg., and thoroughly tested it. He had also to increase the area of the aeroplanes, which originally covered from 8 to 10 sq. m., to 14 to 16 sq. m., by building a double-deck flying machine (fig. 93), and accustom himself to flying with the extra weight of the motor. As soon as he was sufficiently expert with this he proposed to build a new flying machine, with which he could make at first quite small wing-strokes. After this, he wished to gradually increase the strokes. Otto Lilienthal hoped thus to build up the subject of artificial flight on a new basis ; but an unexpected calamity removed him, all too early, from his promising sphere of work. In testing a horizontal steering arrangement, he fell suddenly from a height of 15 m. on to quite uncleared ground and broke his spine.

In the following section we repeat the introduction to artificial flight which he wrote for the first (German) edition of this handbook in 1895, seeing that we hold his ideas and researches as a dear and valuable legacy, and deliver them up to posterity to boldly investigate and continue them.

FIG. 93.—Lilienthal's flight in his double-decker from his artificial hill in Lichterfeld. (Photographed by A. Regis, Berlin.)

(*Cf. Z. f. L.*, 1891, p. 153.—Lilienthal, *Über Theorie und Praxis des freien Fluges*, p. 286; *Über meine diesjährigen Flugversuche*, 1892, p. 277; *Über den Segelflug und seine Nachahmung*, 1893, p. 259; *Die Tragfähigkeit gewölbter Flächen beim praktischen Segelfluge*, 1894, p. 143; *Allgemeine*

Gesichtspunkte bei Herstellung und Anwendung von Flugapparaten; *The Aeronautical Annual*, edited by J. Means, Boston, 1896, p. 7.—Lilienthal, "Practical Experiments for the Development of Human Flight."

PART II.

ARTIFICIAL FLIGHT.

BY OTTO LILIENTHAL.

§ 1. GENERAL CONSIDERATIONS.

A. Artificial flight may be defined as that form of aviation in which a man flies at will in any direction, by means of an apparatus attached to his body, the use of which requires personal skill. Artificial flight by a single individual is the proper beginning for all species of artificial flight, as the necessary conditions can most easily be fulfilled when a man flies individually.

Reasons.

1. The increasing size of the apparatus makes the construction more difficult in securing lightness in the machine; therefore the building of small apparatus is to be recommended.
2. The difficulty of rising into the air increases rapidly with the size of the apparatus. The uplifting of a single person is therefore more easily attained than that of a large flying machine loaded with several persons.
3. The destructive power of the wind increases with the size of the apparatus. A machine intended to serve for the flight of but a single person, is most easily governed in the air.
4. The employment of small patterns of flying machines does not permit of any extended observation, because stable flight cannot be maintained for any length of time automatically. Therefore experiments in actual flight will only be instructive when a man participates in the flight, and maintains stable equilibrium at will.

B. Experiments in gliding by a single individual, following closely the model of bird gliding, is the only method which permits us, beginning with a very simple apparatus and in a very incomplete form of flight, to gradually develop our proficiency in the art of flying.

Reasons.

1. Gradual development of flight should begin with the simplest apparatus and movements, and without the complication of dynamic means.
2. The sailing flight of birds is the only form of flight which is carried on for some length of time without the expenditure of power.
3. With simple wing surfaces, similar to those of the bird, man also can carry out limited flights without expending work, by gliding through the air from elevated points in paths more or less descending.
4. The peculiarities of wind effects can best be learned by such exercises.
5. The contrivances which are necessary to counteract the wind effects can only be understood by actual practice in the wind.
6. The supporting powers of the air, and of the wind, depend on the shape of the surfaces used, and the best forms can only be evolved by free flight through the air.
7. The maintenance of equilibrium in forward flight is a matter of practice, and can only be learned by repeated personal experiment.
8. Experience alone can teach us the best forms of construction for sailing apparatus, in order that they may be of sufficient strength, very light, and most easily managed.
9. By practice and experience, a man can (if the wind be of the right strength) imitate the complete sailing flight of birds, by availing himself of the slight upward trend of some winds, by performing circling sweeps, and by allowing the air to carry him.
10. The efficiency of sailing flight upon fixed wings may be increased by flapping the wings, or portions of the wings, by means of a motor.
11. With a proper apparatus, which may simultaneously be used for sailing and rowing flight, a man may obtain all the advantages of bird flight for a certain duration of flight, and may extend his journey in any direction, with the least expenditure of power devisable.
12. Actual practice in individual flight presents the best prospects for developing our capacity until it leads to perfected free flight.

§ 2. SPECIFIC CONSIDERATIONS.

As a due preparation for eventual human flight, practice in sailing flight, without the use of beating wings, constitutes the

best beginning. The apparatus for this purpose must have the shape of a bird's wings when extended. Its soaring and carrying action is consequent upon the favourable air pressures produced on surfaces shaped like the wings of birds.

Wings provided with a slightly arched profile, when moving horizontally through the air, at an angle of incidence approximately horizontal, will experience an air pressure which will tend to lift strongly while producing but little resistance to forward motion. With a proper position of the wings, when sailing forward in a path slightly inclined downwards, the drifting effect of the air pressure entirely disappears, while a strong lift remains. Therefore, a wind with a very slight upward trend will have an uplifting effect without driving the

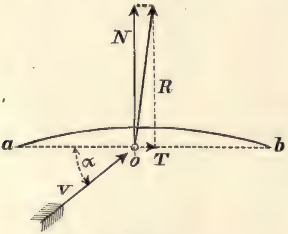


FIG. 94.

apparatus backwards. In this way, momentary hovering at one spot is possible in the air, and it is even possible to sail against the wind without loss of elevation.

Favourable results are obtained when the profile of the wings is arched upwards (in section) about $\frac{1}{18}$ to $\frac{1}{12}$ of their width.

Suppose a wing with the profile *a b* (fig. 94) to be struck by the wind, at an angle α and with a velocity v, there will be generated an air pressure R, which generally is not normal to the chord *a b*, but is the resultant of a force N normal to the chord, and of another force T tangential to the chord. If we call F the area of the wing, then :—

$$\text{The normal pressure } N = \eta \times 0{\cdot}13 \times F \times v^2.$$
$$\text{The tangential pressure } T = \theta \times 0{\cdot}13 \times F \times v^2.\text{[1]}$$

[1] $0{\cdot}13 \times F \times v^2$ in metric measures $= 0{\cdot}0054 \times F \times v^2$ in British units and miles per hour.

The following table shows that arched surfaces still possess supporting powers when they are struck by the air at an acute angle from above—that is to say, when α becomes negative.

TABLE GIVING η AND θ FOR DIFFERENT VALUES OF α.[1]

α	η	θ	α	η	θ
− 9°	0·000	+0·070	16°	0·909	−0·075
− 8	0·040	+0·067	17	0·915	−0·073
− 7	0·080	+0·064	18	0·919	−0·070
− 6	0·120	+0·060	19	0·921	−0·065
− 5	0·160	+0·055	20	0·922	−0·059
− 4	0·200	+0·049	21	0·923	−0·053
− 3	0·242	+0·043	22	0·924	−0·047
− 2	0·286	+0·037	23	0·924	−0·041
− 1	0·332	+0·031	24	0·923	−0·036
0°	0·381	+0·024	25	0·922	−0·031
+ 1	0·434	+0·016	26	0·920	−0·026
+ 2	0·489	+0·008	27	0·918	−0·021
3	0·546	+0·000	28	0·915	−0·016
4	0·600	−0·007	29	0·912	−0·012
5	0·650	−0·014	30	0·910	−0·008
6	0·696	−0·021	32	0·906	−0·000
7	0·737	−0·028	35	0·896	+0·010
8	0·771	−0·035	40	0·890	+0·016
9	0·800	−0·042	45	0·888	+0·020
10	0·825	−0·050	50	0·888	+0·023
11	0·846	−0·058	55	0·890	+0·026
12	0·864	−0·064	60	0·900	+0·028
13	0·879	−0·070	70	0·930	+0·030
14	0·891	−0·074	80	0·960	+0·015
15	0·901	−0·076	90	1·000	−0·000

The resisting components of the air pressure T change, with angles exceeding 3°, into propelling components, which at an angle of 15° become equal to $\frac{1}{12}$ of the lift, and do not disappear entirely until 30° is reached.

In the case of the more usual inclinations of sailing surfaces in flight, air resistances are produced which, acting as a strong lifting force, also act as a force propelling forward.

A current of air rising at an upward trend of 3° above the

[1] **This table for η and θ was deduced from the diagrams on Plate VI. in Lilienthal's book, *Bird Flight as the Basis of the Flying Art*.**

horizontal, acts upon a horizontal arched surface with a strong uplift without driving it back. (This is the principal reason for the soaring of birds.)

At 3°, 32°, and 90° the air pressure will be normal to the chord of the wing profile.

How much better adapted arched wings are for flight than plane surfaces is apparent from figs. 95 and 96.

The plane surface in fig. 95, ab, and the curved surface cd,

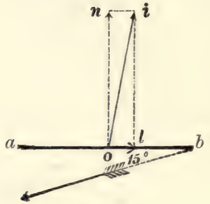


FIG. 95.

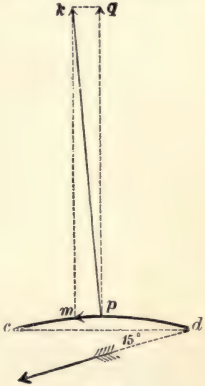


FIG. 96.

fig. 96, are of equal size, and are moved against the air at an angle of 15° at the same speed. The air[1] pressure on the plane surface is $o\,i$, and that of the curved surface is $p\,k$. The former has little lifting power, while it acts to check the forward motion; but the latter, $p\,k$, has a strong lifting power, and tends to produce forward motion.

At the same velocity, and with the same angle of incidence, the arched surface has a far greater lifting power than the plane; and while, for propelling the plane surface, a further expenditure of force is necessary, the arched surface in this case exerts a force forward which can be utilised.

[1] "Resultant pressure."

By the use of the table, all phenomena of soaring with curved surfaces can be calculated.

EXAMPLE.

A sailing surface of 10 sq. m. (107·6 sq. ft.) is raised towards the front at an angle of 3° to the horizon, and glides downwards in calm air at an angle of 6°. The angle of incidence α of the "relative wind" will then be 9°. With a velocity of 10 m. (32·8 ft.) per second there will be created:—

$$\text{Normal pressure } N = 0{\cdot}8 \times 0{\cdot}13 \times 10 \times 10^2 = 104 \text{ kg.}$$
$$\text{Tangential pressure } T = 0{\cdot}042 \times 0{\cdot}13 \times 10 \times 10^2 = 5{\cdot}46 \text{ kg.}$$

T does not act as a resistance but as a propelling force; but N is inclined backward by 3°, and acts as a retarding force whose magnitude is

$$N \times \sin 3° \text{ or } 104 \times 0{\cdot}052 = 5{\cdot}40 \text{ kg.}$$

Now, as the propelling and the retarding forces balance, there will be an equiponderance in the motion, and hence it follows that an arched carrying surface 10 m. in area can sustain a load of 104 kg. with a velocity of 10 m. at an angle of 6° downwards.

If other resistances come into play, they will have to be separately considered.

§ 3. DIRECTIONS FOR PRACTICAL FLIGHT.

Let us begin with practice in sailing flight. The apparatus has 10 to 15 sq. m. (107 to 161 sq. ft.) carrying area, and weighs about 20 kg. (44 lbs.) if built of willow wands covered with shirting. The greatest width of the wings should be not over $2\frac{1}{2}$ m. (8·2 ft.), and the spread from tip to tip not over 7 or 8 m. (23 to 27 ft.), so that the equilibrium may be maintained by a simple movement of the body, altering the centre of gravity. A fixed vertical rudder, placed as far as possible to the rear, facilitates getting squarely into the wind. A horizontal rudder prevents tipping towards the front.

For reasons of stability, the versine of the wing curvature should be less than $\frac{1}{12}$ of the breadth, preferably $\frac{1}{18}$ to $\frac{1}{15}$. The apparatus is held fast by seizing it with the hands and laying the lower part of the fore-arm between cushions, so that the legs remain free for steering, running, or landing.

The best place for practice is a bare hill with a slope of about 20° in every direction.

You hold the apparatus inclined towards the front, take a run against a gentle breeze, and, keeping the apparatus horizontal, make a short leap into the air. In landing, the apparatus is to be lifted towards the front to check the velocity. When the operator feels able, the sailing may be gradually extended. If one side of the apparatus is lifted by a gusty wind, the centre

FIG. 97.—Change of centre of gravity by a change of position of the body.

of gravity must be moved to that side in order to restore equilibrium. The longest sailing flights are obtained when the front edge of the sail surface lies a very little lower (about 2°) than the rear edge In a calm the velocity of sailing will be about 10 metres per second (22 miles per hour), and the course will be from 6° to 8° downwards.

Figs. 97 and 98 show the progress of such a flight, and the appearance of an apparatus which folds up.

If an apparatus actuated by a motor is to be used, it should, in the beginning, be operated in sailing flight only. Gradually,

and after a landing can be performed without trouble,

FIG. 98.—Flight by Lilienthal. (Photograph by A. Krajewsky, Berlin.)

the propelling portions of the apparatus may be put into operation.

PART III.

ARTIFICIAL FLIGHT.

BY OCTAVE CHANUTE,
Consulting Engineer, Chicago, Illinois; Past President of the American Society of Civil Engineers.

§ 1. PILCHER.

LILIENTHAL's sad fate doubtless deterred many searchers from emulating him, but there were a few who thought his advice and his practice sound, and who were so far attracted by a partially solved problem as to experiment in gliding flight.

Principal among these was Mr Percy S. Pilcher, a young English marine engineer. He experimented altogether on five machines of his own. With the first in June 1895 (14 sq. m.; weight, 23 kg.), he found that setting the wings at a considerable dihedral angle, like those of a descending hawk, made the apparatus difficult to handle in a side wind (*The Practical Engineer*, Manchester, England, 6th December 1895, p. 484). It did much better when altered to resemble the attitude of a gull (Pilcher, in *Nature*, London, 20th February 1896, p. 365). The glides were 15 to 120 m. long, at heights of 2 to 6 m. above the ground. Having had many breakages, he next built a strong machine (16 sq. m.; 36·5 kg.), but found this too heavy to handle, and also that it is a mistake to apply the weight too far below the surfaces.

In 1896, a third apparatus (16 sq. m.; 23 kg.) enabled him to make many good glides. He resorted in light breezes to the method of towing the machine with a light line running through five-fold multiplying gear pulled by running boys. With this a height of 21 m. was attained across a valley, and upon the breaking of the string a safe gliding descent was made (*Nature*, London, England, 12th August 1897, p. 345). A pull of about 13·7 kg., indicating a net expenditure of two horse-power, was sufficient to impart a speed of 11 m. per second, or enough for horizontal support (*Aeronautical Annual*, 1897, Boston, U.S.A., p. 144).

Thereupon Pilcher patented a form of construction which he considered preferable to Lilienthal's (similar to Mr Chanute's shown in fig. 100), and also built an oil-engine of four horse-power. Before applying the latter, more gliding experiments were deemed requisite to learn the art of balancing. These were successful until October 1899, when, on giving an ex-

hibition to distinguished guests at a gentleman's park near Rugby, a weak part of the machine broke while in the air upon the second flight. Pilcher fell headlong some 10 or 12 m., and died thirty-four hours later. He was thirty-two years of age, a skilled inventive engineer, and a most lovable character. He had built, but not tried, another machine to which the oil-engine was to be applied, being a three-surfaced gliding machine somewhat similar to one of Mr Chanute's.

The advances achieved by Pilcher, who, like Lilienthal, depended upon shifting the centre of pressure to maintain the equilibrium, may be stated to consist of the following:—

1. The demonstration that a considerable dihedral angle in the wings produces diminished stability in side winds.
2. That an unduly low centre of gravity makes the apparatus much more difficult to control.
3. That a machine can safely be raised by towing it against the wind like a kite.
4. That light wheels at the front are convenient to move the machine about and to absorb shocks in landing. (See *The Aeronautical Journal*, London, 1897—No. 2, p. 1; No. 4, p. 24; 1898, pp. 5, 56; 1899, p. 86; 1900, p. 118).

§ 2. CHANUTE.

Having already published a series of articles reviewing previous proposals and experiments of flying machines (*Progress in Flying Machines*, M. N. Forney, New York, 1894), Mr O. Chanute of Chicago, Illinois, U.S.A., came to the conclusion that equilibrium was the most important problem to solve, and he thought that it might be made automatic by reversing previous practice, and making the surfaces movable instead of the man. Inspired by the example of Lilienthal, he began to experiment in 1896, and built that year five full-sized machines covering four types.

The first (in order to test the known before passing to the unknown) was a Lilienthal machine, built by Chanute's assistant, Mr A. M. Herring, who had already experimented with two similar machines. It was found to require movements fore and aft of as much as 130 mm. on the part of the operator, and was discarded as dangerous after making about one hundred glides, about a month before Lilienthal's sad death came to confirm this decision.

The "Multiple Winged" machine, constructed at the same time, was next tested. It had originally twelve wings, but, in the regrouping, one pair was taken off to avoid striking the ground. Its final shape is shown in fig. 99. With this the

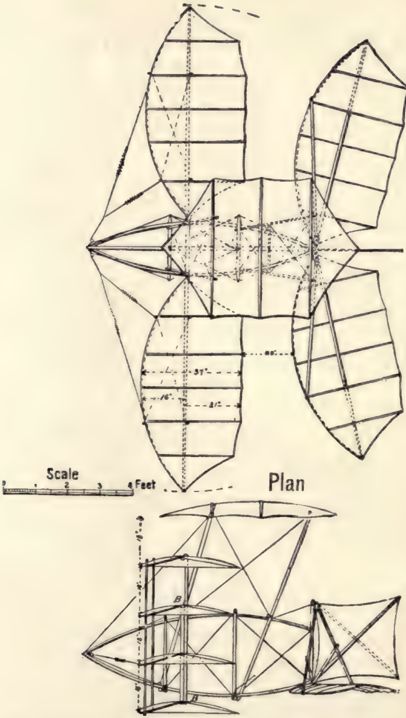


FIG. 99a.—Chanute's multiple-winged machine. (Side elevation.)

movements of the operator were reduced to 40 mm., the gliding angle of descent was 12°, and the power required was 2·53 H.P. (*I.A.M.*, 1898, No. 2, and 1899, No. 2). The wings are on pivots, retroacting, and swing horizontally, so as to bring the centre of pressure to coincide with a vertical line

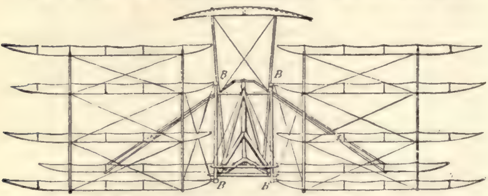


FIG. 99*b*.—Chanute's multiple-winged machine. (Front elevation.)

passing through the centre of gravity. After making about three hundred glides, the wings became so warped that further experiments were made with another style of machine, built the same season, with which still better results were obtained.

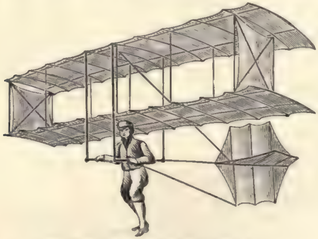


FIG. 100.—Chanute's double-decker.

This was the so-called "Double Deck," shown in fig. 100. Its main frame consisted in a rectangular bridge truss of wood, braced by steel wires, carrying aerocurve surfaces arched $\frac{1}{12}$ on the top and bottom booms. To the rear was a rudder attached by an elastic device designed by Mr Herring. In operation, this caught the relative wind either upon its upper or lower surface when wind gusts occurred, and altered the

angle of incidence of the supporting surfaces, to meet the circumstances. The apparatus weighed 10·67 kg. With a total weight of 81 kg., including the operator, who was upright, the speed required for support was 10 m. per second, and the

FIG. 101.—Chanute's three-decker, 1902.

angle of descent varied from $7\frac{1}{2}°$ to $11°$, indicating an expenditure of 2 H.P. net. The movements required were 60 mm. Some seven hundred glides were made with this apparatus, and not the slightest accident occurred during any of Chanute's experiments (*Aeronautical Annual*, 1897, Boston, U.S.A., p. 30).

Still he believed the application of a motor to be wholly premature. Although rapid in action, the two principles tested did not act quickly enough to prevent all movements on the part of the operator. Chanute accordingly tested a third principle with models, that of pivoting the surfaces to rock fore and aft on a stationary pivot; and he built a full-sized machine, in 1902, with which good results have been attained.

FIG. 102.—Flight with Chanute's three-decker, 1902.

The peculiarities pertaining to his experiments are:—

1. Research for automatic equilibrium exclusively (*Journal Western Society of Engineers*, Chicago, December 1897).
2. Making the surfaces movable instead of the man.
3. Superposing surfaces on a bridge-like truss.

§ 3. HERRING.

Mr A. M. Herring, of Chicago, believing that the equilibrium was sufficiently developed, after building another "Double Deck" machine in 1897, proceeded to apply a motor and screw propeller. He first built a gasolene engine; but this proving unsatisfactory, he next tested a compressed air engine. As with

this no flight could be obtained of more than 15 to 22 m., he has turned his attention to a compound steam-engine, with which he expects success ; he also has built another very light gasolene engine.

§ 4. HARGRAVE.

Mr Lawrence Hargrave, of Sydney, New South Wales, who has built a large number of dynamic flying machines, and invented the cellular or box form of kite which bears his name, tried in 1898 and 1899 a number of very interesting experiments with soaring kites, with which he produced results very much akin to "aspiration" (*Aeronautical Journal*, London, 1898, pp. 29, 80 ; 1899, p. 51).

Instigated by Chanute's articles on soaring flight, which pointed out the difference between the flying and the soaring wing, he made a series of experiments upon the path of air currents under arched surfaces, and finally produced various kites which, under peculiar circumstances, would advance a short length of time against a wind which he believed to be horizontal. So decided was this action that Hargrave was led to conclude that birds soared in strictly horizontal winds, and that soaring sails might furnish propulsion, not only to flying machines, but to ships against the wind. Other experimenters have failed to reproduce these effects; but Mr A. A. Merrill (*Aeronautical Journal*, London, 1899, p. 65), Secretary of the Boston (U.S.A.) Aeronautical Society, has tested the comparative merits of modifications of the form recommended by Hargrave. It is found that the "Tangential" propelling force, announced by Lilienthal, does exist, but that it is insufficient to overcome the whole of the resistances.

§ 5. WRIGHT.

In 1900, 1901, and 1902, Messrs Wilbur and Orville Wright, of Dayton, Ohio, U.S.A., achieved a considerable advance over all previous practice. They were bold enough to be the first to place a man prone upon a gliding machine, instead of upright (for safety in alighting), and they used surfaces of twice the area which previous experimenters had found it practicable to handle in the wind. Their first machine had a surface of 15·3 sq. m., or about the same as Pilcher's ; but their 1901 machine had two surfaces 1·73 m. apart, each a rectangle 6·7 m. from tip to tip, 2·13 m. wide, and arched $\frac{1}{19}$, with a net supporting surface of 27 sq. m. They discarded the tail, and substituted for it a hinged horizontal rudder at the front,

set at a negative angle of 7°, which could easily be operated by the aviator while under way. Their theory was that the man should constantly balance and guide the machine by the action of the rudder, steering to the right or left by warping one wing or the other—light strings leading to his hands for that purpose. Fig. 103 shows this apparatus in the air. The frame was of wood and steel wire, forming a bridge truss similar to that of Chanute's "Double Decker," but with an improvement in the mode of tightening up the wires. With it something like one hundred glides were made from a sandy hill in North Carolina, U.S.A., in July and August 1901, without any

FIG. 103.—Wright's double-decker. (Photograph by O. Chanute.)

accident, and at angles of descent of 9 to 10°, indicating an expenditure of $2\frac{1}{2}$ H.P. for an aggregate weight of 109 kg. The control of the machine by the rudder in front was found to be even better than had been hoped, and the landings were made with entire safety at speeds of even 10 m. per second.

Valuable experiments were also made with the unloaded machine, in horizontal winds, to determine its "lift" and its "drift" at various angles of incidence. It was found not only that the head resistance of the framing (owing to its peculiar construction) was less than that estimated by previous experimenters, but that there must be a "Tangential" force, as discovered by Lilienthal, but questioned by other aviators.

The experiments of 1902 marked another great advance.

The machine had 28·44 sq. m. of sustaining surfaces, and proved still better under control. It enabled glides to be made at angles of descent of 6° to 7°, and supported 50 to 66 kg. per H.P., or 25 per cent. more than had previously been achieved.

These experiments, which mark a decided advance in the technics of flight, have been completely and lucidly discussed in an address by Mr Wilbur Wright to the Western Society of

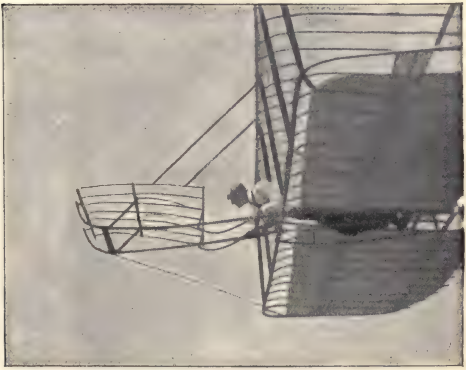


FIG. 104.—Wright's double-decker in flight. (Photograph by O. Chanute.)

Engineers of Chicago, which will be found in its *Journal* for December 1901. His own conclusions are as follows:—

1. That the lifting power of a large machine, held stationary in wind at a small distance from the earth, is much less than the Lilienthal table and our own laboratory experiments would lead us to expect. When the machine is moved through the air, as in gliding, the discrepancy seems much less marked.
2. That the ratio of drift to lift in well-shaped surfaces is less at angles of incidence of 5° to 12° than at an angle of 3°.
3. That in arched surfaces the centre of pressure at 90° is near the centre of the surface, but moves slowly forward as the angle becomes less, till a critical angle, varying

with the shape and depth of the curve, is reached, after which it moves rapidly towards the rear till the angle of no lift is found.

4. That with similar conditions, large surfaces may be controlled with not much greater difficulty than small ones,

FIG. 105.—Landing with Wright's double-decker. (Photograph by O. Chanute.)

if the control is effected by manipulation of the surfaces themselves rather than by a movement of the body of the operator.

5. That the head resistance of the framing can be brought to a point much below that usually estimated as necessary.

6. That tails, both vertical and horizontal, may with safety

be eliminated in gliding and other flying experiments.

7. That a horizontal position of the operator's body may be assumed without excessive danger, and thus the head

FIG. 106.—Wright's double-decker with vertical rudder, 1902. (Photograph by O. Chanute.)

resistance reduced to about one-fifth that of the upright position.

8. That a pair of superposed, or tandem, surfaces has less lift in proportion to drift than either surface separately, even after making allowance for the weight and head resistance of the connections.

20

These conclusions were practically confirmed by the experiments of 1902, but it was found useful to add a vertical tail to assist in the steering and to maintain the course. A paper giving an account of the advance obtained was read by Mr Wright before the Western Society of Engineers, and will be found in its *Journal* for August 1903.

The apparatus could now be controlled so well that Wright brothers deemed it safe to pass on to the construction of a full flying machine equipped with a motor and propeller. This was done in 1903, and on the 17th of December of that year, after many trials and modifications, they had the satisfaction of making four dynamic flights from level ground against a wind of 10 m. per second—the first flight being of about 12 seconds, and the last of 59 seconds, when 260 m. were covered at a height of about 2 m. from the ground.

These experiments were resumed in 1904, and during that season one hundred and five flights were made, showing minor defects which required slight changes in the construction, more particularly when circular flights were attempted, no less than four complete circles around a field having been made on several occasions. There were some breakages from awkward landings, of course; but no accidents occurred to the operators, who took turns in making the flights.

In 1905 the work was continued by further perfecting the apparatus, and by learning its use and control under all circumstances of flight and of wind. Having spent a good deal of time and money in developing their machine to efficiency, the Wright brothers do not wish as yet to make its construction known.

At the meeting of the Aëronautical Society of Great Britain, held in London, 15th December 1905, Mr Alexander read the following letter from the Wright brothers, dated 17th November 1905:—

"We have finished our experiments for this year after a season of gratifying success. Our field of experiment, which is situated 8 miles east of Dayton, has been very unfavourable for experiment a great part of the time, owing to the nature of the soil and the frequent rains of the past summer. Up to 6th September we had the machine out on but eight different days, testing a number of changes which we had made since 1904, and as a result the flights on these days were not so long as our own of last year. During the month of September we gradually improved in our practice, and on the 26th made a flight of a little over 11 miles. On the 30th we increased this to 12¼ miles, on 3rd October to 15⅓ miles, on 4th October to 20¾ miles, and on the 5th to 24¼ miles. All of these flights were made at about 38 miles an hour, the flight of the 5th October occupying

thirty minutes three seconds. Landings were caused by the exhaustion of the supply of fuel in the flights of 26th and 30th September and 8th October, and in those of 3rd and 4th October by the heating of bearings in the transmission of which oil cups had been omitted. But before the flight on 5th October oil cups had been fitted to all the bearings, and the small gasolene can had been replaced with one that carried enough fuel for an hour's flight. Unfortunately we neglected to refill the reservoir just before starting, and as a result the flight was limited to thirty-eight minutes. We had intended to place the record above the hour, but the attention these flights were beginning to attract compelled us to suddenly discontinue our experiments in order to prevent the construction of the machine from becoming public.

"The machine passed through all of these flights without the slightest damage. In each of these flights we returned frequently to the starting point, passing high over the heads of the spectators.—ORVILLE WRIGHT."

§ 6. FERBER.

Captain F. Ferber, of the French Army, became a neophyte of Lilienthal in 1898, and built successively four gliding machines with which he experimented near Nice, France, upon most unsuitable ground (*Les Progrès de l'Aviation*. A lecture—F. Ferber. Berger-Levrault, publishers, Paris.) The results were unsatisfactory, but he possessed too much pluck to become discouraged. Having entered into communication with Chanute in 1901, he thereafter experimented with double-surfaced machines such as had been developed in America. He obtained satisfactory glides at Beuil in 1902 and at Le Conquet in 1903, and in the latter year he thought himself sufficiently advanced to warrant the addition of a motor and propeller. This step proved premature. The apparatus upon a preliminary test, suspended from a long rotating arm (*L'Aérophile*, February 1903–February 1905), did not attain sufficient speed from its propeller to sustain itself, and the equilibrium was doubtful. He then built a sixth gliding machine, with improvements, and in 1905 built another flying machine with a more powerful motor, from which better results are to be expected. He is now (August 1905) attached to the Aeronautical establishment of the French War Department at Chalais-Meudon.

§ 7. ARCHDEACON.

Impressed with what had been accomplished in America with gliding machines, Mr E. Archdeacon of Paris inaugurated a

fund in 1903 to promote similar performances, and he built a machine of his own. This was tested on the sand dunes of Berck-sur-Mer, in April 1904, with some encouraging results (*L'Aérophile*, March 1904–April 1904), but the construction was found defective in its connections and concavity of wing, and the machine was rebuilt and enlarged. Meanwhile Mr Archdeacon, in connection with the Aero Club of France, promoted an exhibition in Paris, in February 1905, of gliding and proposed flying machines (*L'Aérophile*, Maich 1905), at which some forty models were entered, and some shown in action, by thirty exhibitors. Some of these models were both novel and promising, and further exhibitions are to be made.

His new modified gliding machine being completed, Mr Archdeacon tested it near Paris, in March 1905, by having it towed by an automobile (*L'Aérophile*, April 1905), but it was loaded with a bag of sand instead of a pilot. It rose grandly into the air, then the tail became disarranged and the apparatus fell to the ground. It was broken, but not beyond repair.

Realising the danger of alighting upon hard ground, Archdeacon next had his rebuilt gliding machine (shaped somewhat like a Hargrave kite) tested upon the Seine, in June and July 1905. The apparatus rested upon the water by means of light floats, and was towed by a fast motor boat (*L'Aérophile*, July 1905) at a speed of 40 kilom. per hour. It was mounted by Mr Voisin and rose some 17 m. into the air, glided some 150 m., and alighted gently on the water. The second trial, in July, resulted somewhat less favourably, and the operator took a compulsory bath. On the same occasion a somewhat smaller gliding machine, the design of Mr Louis Blériot (*La Vie Automobile*, 29th July 1905), was tested in the same manner, with inferior results (*I. A. M.*, 1905, No. 11).

§ 8. ESNAULT-PELTERIE.

A series of very interesting experiments with a gliding machine similar to that of Wright brothers were made in France, near Wissant, in 1904, by Mr R. Esnault-Pelterie, a young engineer (*L'Aérophile*, June 1905). They were intended to verify the American statements. The results were nearly equal to those obtained by Wright brothers the first year they experimented. It was demonstrated that it was possible to glide at an angle of 1 in 10, and experience was gained which will doubtless be utilised later ; for nothing but practice, practice, practice will produce adequate advance.

§ 9. MONTGOMERY.

After some preliminary studies and trials, Mr J. J. Montgomery, a professor in Santa Clara College, California, built a full-sized gliding machine, closely resembling the flying machine of Langley in outward appearance, but with movable parts which enabled it to be steered when descending under the influence of gravity, for it had no motor or propeller. He found a parachute jumper, J. M. Maloney, who was daring enough to attempt the unprecedented feat of gliding down with this apparatus from a height of 1000 m. or more.

The apparatus consisted of two rectangular wings or arched surfaces placed in tandem, each 7·31 m. across and 1·15 m. wide, thus giving a supporting surface of 16·82 sq. m., and a weight of 19·1 kg. The operator weighed 70 kg. The rear wing was so fastened to the frame or spine as to be capable of motion in various directions by wires ; and there was, in addition, a vertical keel and also a rudder, the latter being formed of two half circles at right angles to each other, made movable for both horizontal or vertical steering.

The apparatus was first privately tested in March 1905. It was raised to various heights, being suspended by ropes under a hot-air balloon, and then cut loose. On the sixth trial the height was about 1000 m. When cut loose, the machine first swooped down and then began to glide at a small angle of descent. It could be turned by the operator to glide in a circle either to the right or left, or be made to dart steeply downward, or even to rise a little until the velocity diminished unduly ; all these movements being produced by changes in the shape of the surfaces induced by the operator. The time occupied in the descent from 1000 m. was about thirteen minutes, and the apparatus alighted upon the ground at each trial as gently as a bird.

The machine was publicly tested at Santa Clara, on 29th April 1905 (this being an anniversary of the College), in the presence of many invited guests and representatives of the press. It was lifted by the balloon on this occasion to a height of about 1200 m., and put through its paces when cut loose. The operator caused it to sweep in circles, to make deep dives, and to imitate the manœuvres of a soaring bird, in order to demonstrate that the control was well within his powers. He finally alighted gently in a field previously designated about 1 km. away from the starting-point, the ascent and descent having occupied nineteen minutes (*Scientific American*, 20th May 1905).

Again the apparatus was publicly tested on 18th July, and this culminated in a tragedy. When the ascent was made, one of the ropes failed to release properly, and, it is believed, cracked

or broke a mast or strut supporting the guy wires. The operator was unaware of this, and at a height of some 600 m. he cut loose. He glided downward about 400 m., and then undertook to make a "deep dive" at a steep angle. The additional pressure thrown upon the back wing collapsed it, and poor Maloney lost control of the machine, crashed down to the earth, and died some twenty minutes afterwards.

This deplorable accident is the only one which has occurred since that to Pilcher.

Thus it is seen that, notwithstanding these accidents, the methods inaugurated by Lilienthal have produced great and promising results. Searchers have made various changes in the arrangements of the gliding machine, some of which have proved to be improvements—the trussed two-surfaced machine being now the favourite.

The forms and arrangements of the sustaining surfaces are the important things to evolve in order to (1) maintain stability, (2) obtain maximum support, and (3) reduce resistance to a minimum. Nothing but actual practice will work out these points.

It is probable that the time has now arrived when it is reasonably safe to apply a motor and a propeller to a gliding machine which has proved itself to be thoroughly under the control of the operator, and that we are now not far distant from the appearance of a true and efficient flying machine.

§ 10. COMPUTATIONS.

Lilienthal says above, after pointing out the advantage of the arched surface in resultant pressure over the plane, and giving an example in which he computes the supporting power (Lift), the resistance of the surface (Drift), and the propelling power (Tangential), that: "If other resistances come into play, they will have to be separately considered."

In point of fact, these other resistances, which arise from those of the framing and of the body of the aviator, are generally much greater than the "Drift." They are termed "Head Resistance" by Chanute, and were computed by him for his "Multiple Wing" machine at 12·86 kg., while the "Drift" proper was 5·49 kg. (*I. A. M.*, 1899, No. 2). His angles of descent and calculations seemed to confirm the coefficients of Lilienthal; but since then Wright has diminished the "Head Resistance" nearly one-half, by imbedding the main spars in the cloth, and by placing the man in a horizontal position on the machine. This has resulted in bringing into question the accuracy of the values of η (Normal pressure) and of θ (Tangential) in Lilien-

thal's table, which other experimenters before had said were not to be trusted.

The Wrights thereupon made laboratory experiments of their own upon various forms of arched surfaces, and confirmed the existence of a "Tangential" propelling force at certain angles, which reduced but did not entirely overcome the "Drift." They found that Lilienthal's coefficients for the Normal η were in excess at small angles, although less so than had been believed, being about 50 per cent. at 0°, about 14 per cent. at +3°, and nearly agreeing at +5°. The coefficients for θ were also too favourable at angles below 10°, the tangentials becoming retarding forces at all angles below 7°, instead of 3°.

They found, moreover, that these approximations were only true when the surface in plan had the outline of the double segment experimented by Lilienthal (*Der Vogelflug*, etc., p. 93). A square surface in plan or a rectangle 6 to 1, arched $\frac{1}{12}$ transversely, gives quite different coefficients. Lilienthal's discrepancies probably resulted from errors in his methods, notably the omission to attach the surfaces tested at their exact centre of pressure. The travel of this is a very important point to consider. On planes, as is well known, the centre of pressure is near the front at 0° of incidence, on a surface square in plan; and it travels slowly backwards as the angle increases, until it reaches the middle of the surface at 90°. On arched surfaces the travel is quite different, and reverses its motion in many cases. Spratt says (private tentative experiments as yet unpublished), for instance, that on a circular arc $\frac{1}{12}$ rise, the centre of pressure is near the rear at 0° of incidence; that as the angle increases, the centre of pressure moves *forward*, passing the middle at about 17°, and continues until it is 41½ per cent. from the front at 30°. It then reverses its motion, and moves slowly backwards until it is 50 per cent. (or at the middle), when an incidence of 90° is reached. On an arc of $\frac{1}{24}$ rise, the centre of pressure is near the rear at 0°, advances and passes the middle at 10°, is 37 per cent. from the front at 30°, reverses its motion and travels to the middle at 90°. This is to be verified.

It follows, therefore, that in applying coefficients to an aeroplane, not only should the arching be taken into account, but also the outline or form in plan, its proportions of length to breadth, its aspect or direction of advance, and the movements of the centre of pressure, which will be found to vary greatly on different arched surfaces.

Professor C. F. Marvin, of the United States Weather Bureau, Washington, says, in a memoir on Aeronautical Mechanics, as yet unpublished:—

"One of the greatest pitfalls in aeronautical mechanics is

found in the idea of the *centre of pressure.* Experiments that have been made to locate this point have yielded various results, and, where full information is available as to the detailed method of making the experiments, it is not difficult to show that the point supposed to be the centre of pressure is only a *point where the action line of a certain force intersects some particular part of the apparatus on the surfaces under experimentation.* By making a proper change in the disposition of the apparatus but yet without affecting the wind pressures, a very different point of intersection can be obtained;

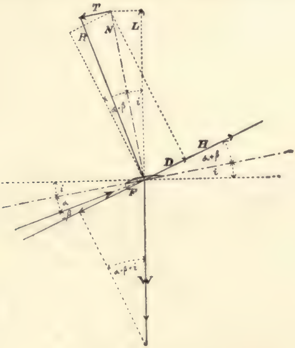


FIG. 107.

in fact, a real centre of pressure has not been located at all because the investigator has failed to form a true conception of the centre of pressure."

These various considerations render it impracticable at this time to give strictly accurate formulæ for computing all the forces which come into action on a flying machine by using Lilienthal's table, but we may obtain fair approximations. The following diagram represents the analysis of the forces as probably considered by Lilienthal, but projected upon the path instead of horizontally.

Provisionally, computations may be made as follows:—

Definition of Terms.

L = Lift, of surface proper, in kilograms.
D = Drift, of surface proper, in kilograms.
T = Tangential.
E = Equivalent head area.
H = Head resistance.
A = Total resistance along the path.
A' = Propulsion along the path.
W = Weight in kilograms.
F = Surface in square metres.
v = Velocity, metres per second.
η = Normal coefficient.
θ = Tangential coefficient.
i = Angle, chord with horizontal.
α = Angle, chord with relative wind.
β = Angle, relative wind with path.
K = The coefficient for air pressure. Lilienthal uses 0·13, but recent experiments indicate 0·096 as more accurate.

Mode of Computation.

1. The "Lift" is to be taken as vertical and opposing gravity. Its value depends upon the particular surface selected, and in horizontal flight it should be equal to the weight. For Lilienthal's experimental surface and table, α being the angle of incidence :—

$$(1)\quad L = K\ F\ v^2\ \eta_\alpha \cos i.$$

There is in addition a small component of lift due to the Tangential, but it will be very small and may be neglected.

2. The "Tangential" may be either a propelling or a retarding force, and pertains to the same angle as the normal, as found in the table. As it is parallel with the chord, its value upon the path will be :—

$$(2)\quad T^p = K\ F\ v^2\ \theta_\alpha \cos(\alpha + \beta).$$

3. The "Drift," computed upon the path, is a retarding force applied at the angle of the chord with the path. Its measure is :—

$$(3)\quad D = K\ F\ v^2\ \eta_\alpha \sin(\alpha + \beta).$$

4. The "Head Resistance" covers that of the exposed framing, car, and aviator. As these are more or less rounded, an

"Equivalent Surface" must be estimated from experiment, and the resulting coefficient E must be multiplied by the air pressure due to the velocity. Its measure is on the path :—

$$(4)\ H = K\,v^2\,E.$$

In certain cases (ascending winds, oblique framing, etc.), the head resistance may have both horizontal and vertical components which have to be allowed for.

5. The aggregate of the drift and of the head resistance as modified by the various contingencies which have been mentioned, gives the total resistance :—

$$(5)\ A = D + H \pm T^p.$$

6. Inasmuch as the propulsion in gliding flight is furnished by gravity, and the forces balance when the motion is uniform, the sum of equation (5) must be equal to

$$(6)\ A' = W \sin(\alpha \pm \beta \pm i).$$

EXAMPLE.

The value of the various elements will seldom be known beforehand, that most uncertain being the efficiency of the surface. Approximate computations made in advance are therefore to be tested by actual results.

If, for instance, it is desired to know at what angle with the horizon a gliding machine will descend at 10 m. per second, the machine being double-decked, with 12·45 sq. m. in two supporting surfaces, these being rectangles about $5 \times 1\frac{1}{4}$ m. each, arched $\frac{1}{16}$, the whole apparatus with its operator weighing 81 kg., and the equivalent head area (man, framing, etc.) being 0·84 sq. m., we may first approximate to the angle of its path in still air, in which the relative wind coincides with the path, and angles α and β are merged into one.

The known elements are :—

$F = 12{\cdot}45$ sq. m.	$v = 10$ metres per second.
$E = 0{\cdot}84$ sq. m.	$K = 0{\cdot}096$.
$W = 81$ kg.	

We first need to know, approximately, the angle required to support the weight. We have :—

$$(1)\ L = 81 \text{ kg.} = K\,F\,v^2\,\eta_\alpha \cos i.$$

As $\alpha + \beta$ form but one angle, and as i will be small, we may

provisionally assume its cosine to be nearly unity. We will have for the coefficient of incidence :—

$$\eta_a = \frac{81}{0{\cdot}096 \times 12{\cdot}45 \times 100 \times \cos i} = 0{\cdot}678 \text{ (where } \cos i = 1).$$

By referring to Lilienthal's table we see that this corresponds nearly to the value of η for 6° (0·696), so that the machine will probably descend in still air at an angle of $6^\circ + i$; hence the lift will be :—

$L = 0{\cdot}096 \times 12{\cdot}45 \times 100 \times 0{\cdot}696 \times \cos i = 83{\cdot}18$ kg., which indicates that the angle is somewhat less than 6°. We next want to know the Tangential. This at 6° acts as a propelling force; hence we have :—

$$(2)\ T^p = K\,F\,v^2\,\theta_a \cos(\alpha+\beta) =$$
$$0{\cdot}096 \times 12{\cdot}45 \times 100 \times -0{\cdot}021 \times 0{\cdot}994 = -2{\cdot}50 \text{ kg.}$$

Next we obtain the drift and the head resistance :—

$$(3)\ D = K\,F\,v^2\,\eta_a \sin(\alpha+\beta) =$$
$$0{\cdot}096 \times 12{\cdot}45 \times 100 \times 0{\cdot}696 \times 0{\cdot}1045 = +8{\cdot}69 \text{ kg.}$$

$$(4)\ H = K\,F\,v^2\,E = 0{\cdot}096 \times 100 \times 0{\cdot}84 = +8{\cdot}06 \text{ kg.}$$

$$(5)\ A = D + H \pm T^p = 8{\cdot}69 + 8{\cdot}06 - 2{\cdot}50 = 14{\cdot}25 \text{ kg.}$$

From the above we can derive the angle i, for we have :—

$$(6)\ A' = W \sin(\alpha+\beta+i) = 14{\cdot}25 \text{ kg.} \quad \text{But } \beta = 0^\circ.$$

Whence $\sin (\alpha + i) = \frac{14{\cdot}25}{81} = 0{\cdot}1759$; therefore $(\alpha + i) = (6^\circ + i)$ $= 10^\circ\ 8'$; therefore $i \times 4^\circ\ 8'$.

So that if the machine is as efficient as the surfaces experimented on by Lilienthal, it ought to descend in still air at an angle of $6^\circ + 4^\circ = 10^\circ$ from the horizon.

This was found to be the case in a calm; but when the wind blew, especially when it had an ascending or a descending trend, the angles of descent varied from 7½° to 11°.

If a motor is to be used, the friction in the machinery and the slip of the propeller must be taken into account.

The above mode of computation will probably require revision as soon as full data for arched surfaces are available.

It is questionable whether it would not be better to consider the air pressures perpendicular to the surface itself, rather than as perpendicular to the chord, as assumed in Lilienthal's tables. Similarly, it is open to doubt whether it would not be better to take the angle α with the line of "no lift" (negative) rather than with the chord.

These questions, as also all others relating to the arching, the shape of surface, the exact coefficients of the various forces, and the movements of the centre of pressure, must be considered as a whole in order to determine the best possible form of wings, and to estimate their probable efficiency. Very many more researches are necessary before satisfactory conclusions can be drawn from them. More rapid progress would result if all the various emulators of Lilienthal, Hargrave, Wright and others would see fit to publish their results as fully and promptly as possible, in order that they might be available for the use of other experimenters.

CHAPTER XII.

ON AIR-SHIPS.

BY MAJOR H. W. L. MOEDEBECK.

A.—HISTORY OF THE DEVELOPMENT OF THE AIR-SHIP.

§ 1. INTRODUCTORY.

THE construction of an air-ship was beyond the range of possibility in the eighteenth century. The problem became only practicable in the last decades of the nineteenth century, when mechanics had so far developed that the construction of machines driven by motors, both light and powerful, was possible.

The twentieth century opens with good prospects that it will see the perfecting of a practical air-ship, which will serve important objects both in science and warfare, and will introduce a new, and at the present day unknown, form of sport.

The numerous extremely fantastical representations which have been made, showing a complete disarrangement of our traffic by air-ships, are foolish. Where other means of communication are wanting, they will, no doubt, be of great use; but the air-ship can obviously have only a limited application, owing to its tonnage and its dependence upon the wind and weather. As its development progresses these limitations will, of course, gradually disappear; but it can never compare favourably with the sea-ship as regards tonnage, even to a thousandth part. On the other hand, it appears to be not beyond the range of probability that velocities of 12 m. per second and upwards may be attained, and that a gradual development in the direction of the dynamical air-ship may be productive of still higher velocities than this.

Every science is made use of in working out the problem of the air-ship, which is, therefore, as international as science itself. Hitherto it has depended for its development, as the following sections will show, on the ideas and work of but few inventors, and on the skilled application of numerous discoveries to aeronautical purposes. In estimating the true value of the initial struggles, in a future epoch, less importance will probably be attached to the value of the discoveries themselves than to the marvellous energy expended in combating the ignorance of the masses while carrying out the ideas.

This is not the place to discuss further the histories of the inventors, with their bitter troubles and false accusers; but it may be pointed out that those who seek out heroes who have devoted life and all to further an ideal, can find a large number in the following pages.

§ 2. THE EIGHTEENTH CENTURY.

1784. 24 Jan. Brisson, a member of the Academy in Paris, read before the latter a memoir on the steering of air-ships. The form of the balloon must be cylindrical, with conical ends. The ratio of the diameter to the length D : L should be as 1 : 5 or 1 : 6, and the smallest cross-sectional area should face the wind (G. Tissandier, *La navigation aérienne, l'aviation et la direction des aérostats dans les temps anciens et modernes*. Paris, 1886).

Brisson proposed to employ oars, but at the same time doubted if the human strength would be sufficiently great to move them. In conclusion, he referred to the use of the differently directed currents of the atmosphere lying above one another.

March. The brothers Robert, mechanics in Paris, received orders to build an air-ship at the cost of the Duke of Chartres. Shape, that of the fish—since it was supposed that the air-ship would swim through air like a fish through water; cylindrical form with hemispherical ends. Ratio, D : L = 3 : 5. Experiments with models on the action of the distribution of weight in the length of the ship, on the stability of the longitudinal axis, and on the force transmitted from the car to the body of the balloon. Length of the body of the balloon, 52 ft.; diameter, 32 ft.; contents, 30,000 cb. ft. The building was carried out in the St Cloud Park. Investigations made on the efficiencies of different air oars in a boat. Result: with two oars of 6 ft. diameter a back pressure of 90 lbs.

1784. March. was attained (45 kg.) in air; with four oars in the middle, 140 lbs. (70 kg.).

The balloon was provided with a double envelope, on Meusnier's recommendation, in order to be able to travel for long periods without loss of gas or ballast.

July. Meusnier, a member of the Academy, and an officer of the Engineers, published in the *Journal de Physique* the first work on the theory of balloon travelling and on balloon voyages of long duration. He recommended an egg-shaped gas-balloon surrounded by a second strong

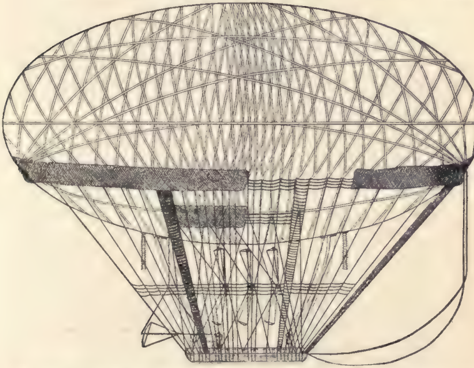


FIG. 108.—Meusnier's proposed air-ship, 1784 (from a drawing from an album in the Archive de la section technique du génie).

envelope. The penetration of gas should be prevented by this means, and might be further hindered by pumping in air between the envelopes by means of two pressure fans, the gas being compressed and made denser and heavier. This action can be stopped by letting out the air again. Meusnier hoped to be able to prevent any loss of gas or ballast by using the air itself for the ballasting of the air-ship. He wished to make the air-ship suitable for a prolonged voyage, and it was to have a wide sphere of action.

By these means he hoped to be able to utilise the

1784. July. different air-currents in the various strata of the atmosphere, for voyaging in any given direction. The motor working by manual labour was only intended for use in a calm. The propeller consisted of three screw blades (*rames tournantes*) arranged in a diagonal rigging behind one another. The car was supported by a strong diagonal rope suspension from the envelope of the balloon. The air-ship was provided with a rudder in the rear and an anchor in front (*Revue de génie*, 1902, p. 145).

6 July. First ascent of the Duke of Chartres' balloon from St Cloud. Passengers: Duke of Chartres, the two brothers Robert, and Collin-Hulin.

In consequence of the double envelope the outflow of gas during the ascent was prevented. Through the presence of mind of the Duke of Chartres, who forced a hole through both balloon envelopes with a flag-staff, danger from bursting was avoided. Descent in the Park of Meudon.

19 Sept. Second ascent from the garden of Tuileries. Passengers: the brothers Robert and Collin-Hulin. Ascent at 11.30 a.m. Owing to one oar having been damaged before the ascent, only two could be used. According to the report of the brothers Robert, they succeeded, in a calm about 4.30 p.m., in completing an ellipse of about 1950 m. minor axis. They then travelled farther in the direction of the wind, without using the oars or steering arrangements. With these they succeeded in deviating their course 22° to the east. Descent near Bethune (Pas-de-Calais), about 190 km. from Paris. (*Mémoire sur les expériences aérostatiques faites par M. Robert Frères, ingénieurs-pensionnaires du Roi.* Paris, 1784.)

David Bourgeois made the first allusion to the use of inclined planes in the ascent and descent of balloons, for the purpose of horizontal forward movements, in his work, *Recherches sur l'art de voler* (1784, p. 88).

1785. March. Professor Christian Kramp of Strassburg, in his *Geschichte der Aërostatischen Maschine*, Part II., in the article on the "Direktion der Maschine" (p. 347), recommends balloon envelopes of the shape of the body produced by the revolution of the segment of a circle about its chord. The horizontal axis of the body must be very much longer than its diameter. He showed also that the car should be strongly bound to the envelope of the balloon, in order to transmit every movement caused by the oars immediately and undiminished to the balloon.

1785. March. The Academy of Lyons offered a prize of 1200 livres for the following exercise:—

"Indiquer la manière la plus sûre, la moins dispendieuse et la plus efficace de diriger à volonté les machines aérostatiques."

Not one of the one hundred and one memoirs sent in solved the problem to the satisfaction of the Academy.

1789. Baron Scott, a captain of the Dragoons, proposed to provide a fish-shaped air-ship with two pockets in the fore and rear portions, which could be drawn into the envelope by an arrangement of levers. The gas in this way is compressed and its density increased. If this pressure is changing and is only exerted in the rear or only in front, then the longitudinal axis of the air-ship must take up an ascending or descending direction (*Aérostat dirigeable à volonté par M. le baron Scott.* Paris, 1789).

§ 3. FALSE IDEAS IN THE EIGHTEENTH CENTURY.

1. It was widely thought that a spherical balloon could be made navigable by oars, wings, mill-wheels, etc. *Cf.* de Morreau, Chaussier et Bertrand. *Description de l'Aérostat: L'Académie de Dijon*, Dijon, 1784; Alban and Vallet, *Précis des expériences faites par MM. Alban et Vallet*, Paris, 1785; Lunardi, London, 15/9/1784; Dr Potain, 17/6/1785. The results given by Blanchard were only for advertisement.

2. It was generally thought that the proportions of the air-ship should resemble those of sea-going ships, and that only the provision of sails and rudders was permissible. The schemes for air-ships of this kind are numerous. On the other hand, many thought that the air-ship met with no resistance in air (*point d'appui*) such as ships meet with in water, and that it was necessary to provide such a resistance artificially before one could use air-sails. (Hénin, *Mémoire sur la direction des aérostats.* Paris, 1801.)

§ 4. THE NINETEENTH CENTURY.

1812. Leppig, a German, built a fish-shaped air-ship (fig. 109) at the cost of the State, in Woronzowo (Russia). A rigid frame beginning at the height of the longitudinal axis. Two fins were attached to the sides, and a tail was provided behind as a horizontal rudder. The lower keel-shaped part formed at the same time the car.

1812. The inflation of the air-ship took five days; the steel springs of the wings broke (*Z. f. L.*, 1882; Frhr. v. Hagen, *Geschichte der militärichen Aëronautik*).

Note.—The principle of the fin propeller was again revived by "Armand Le Compagnon" in 1892, in Paris. The wings of his air-ship were formed after those of the dragon-fly, and in the model were 2·14 m. long and 1·75 m. broad. The length of the experimental balloon was 20·4 m., its diameter 3·5 m., and its cubical contents 156 cb. m.; it had a rigid framework, and four wings on either side at the level of the middle axis. With 232 strokes of the wing per minute it gave a pull of 6·25 kg. (E. Caron, *L'Orthoptère, Ballon dirigeable à ailes*. Paris, 1892.)

1834. The Comte de Lennox built an air-ship of cylindrical form, with conical ends, D : L = 1 : 4, in Paris. Length, 130 ft. = 42·25 m.; diameter, 35 ft. = 11·4 m.;

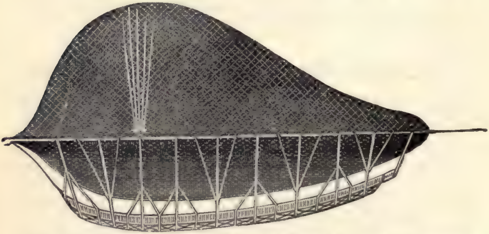


Fig. 109.—Leppig's aerial warship, 1812 (from a drawing in the secret archives of Alexander I. of Russia).

cubical contents, 2800 cb. m. A small balloon, 200 cb. m. contents, was placed inside the larger one for an air filling. Car of length 66 ft. = 21·5 m., fastened under the balloon by means of ropes 18 in. = 0·49 m. long. Above the car the balloon was provided with a long air-cushion, in connection with a valve. The Count wished to alter the height of the air-ship by compressing the air in the air-cushion and in the small inner balloon, in order to be able to travel with the most favourable air-currents. In calm weather the air-ship was to be driven forwards by twenty oar-propellers worked by men.

17 Aug. *Trial.*—The air-ship proved to be too heavy, after inflation, to lift its own weight, and was destroyed by the onlookers (*Manuels Roret*, Depuis-Delcourt, p. 138).

Note.—Numerous similar trials were carried out in the nineteenth century, using human power as motive power and screws

as propellers, all being without result. The following may be mentioned :—

1848. Hugh Bell's air-ship (fig. 110), cylindrical-shaped balloon, L= 17 m , D=6·5 m., with pointed ends, with a keel of metal tubes running from point to point (*i*), to which the car was attached. On either side of the car there were screw propellers worked by hand ; behind was a rudder (*m*). The trials in Vauxhall Gardens were fruitless. (Fahr. v. Biedenfeld, *Die Luftballone*. Weimar, 1862.)

1870. Dupuy de Lôme. Spindle-shaped balloon, L=36 m., D=14·8 m., V=3454 cb. m. An inner air-balloon, V=170 cb. m. Car, 12·4 m. long, with an upper edge 10·5 m. from the axis of the balloon ; diagonal rope suspension ; net covering. Rudder in the form of a triangular sail beneath the balloon and near the rear. Double-winged screws, 9 m. in diameter, to be worked by 4–8 persons. ("Note sur l'aérostat à hélice construit pour le compte

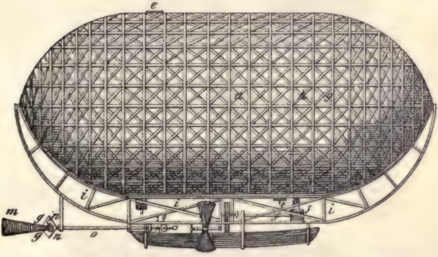


FIG. 110.—Hugh Bell's airship, 1848 (from Frhr. v. Biedenfeld's "Die Luftballone").

de l'État sur les plans et sous la direction de l'auteur." Tome XI., *Mémoire de l'académie des sciences*. Paris, 1872.)

1 Feb. *Trials.*—The air-ship was driven by the wind. Independent velocity about 2·35 – 2·82 m. per second. Deviation from the direction of the wind, 10°.

1879–1882. After numerous trials with models, Baumgarten and Wölfert built a spindle-shaped air-ship, L=17·5 m., D=6 m. The car was firmly suspended from the balloon by seven ropes passing through the balloon, and by rods which were let into holes in the under side of the envelope of the balloon.

Three-winged screws for hand driving.

Trials at Charlottenburg, 5/3/1882, were without result. (*Z. f. L.*, 1882, p. 145.)

1835. 1 Aug. Georg Rebenstein of Nürnberg reverted to the use of the fall of inclined planes to obtain horizontal motion. He founded on this the impossible proposal of a cubical shaped Montgolfiere (fig. 111), which should fold together into a plane when the highest desired point had been

1835. reached, and be navigable during the descent (fig. 112).
1 Aug. (*Luftschiffkunst mit und ohne Beihülfe der Aërostatik*, von Georg Rebenstein, Nürnberg, 1385.)

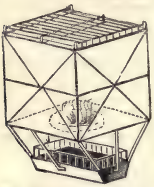


FIG. 111. — Rebenstein's navigable Montgolfiere, 1835 (from the original).

Note.—The principle of the use of inclined plane in combination with a balloon, to obtain a horizontal movement during the ascent and descent, occurs in various further projects—Pétin, 1840. (*Chabannes, nav. aér., notice explicative du système Pétin*, Paris, 1851.) Dr Andrews of Perth, U.S.A., built an air-raft balloon in 1863, which could be inclined at various angles by means of a movable load (Moedebeck, *Handbuch der Luftschiffahrt*, p. 105). William Clark (Engl. Patent No. 3283, 1865) proposed to use a movable sail surface between balloon and car. G. Wellner's (Professor at the Technische Hochschule in Brünn) navigable sail balloon (*Z. f. L.*, 1883, p. 161) was built in Berlin in 1883, and was experimented with, but did not give the results expected (Moedebeck, *Handbuch der Luftschiffahrt*, p. 105, Leipzig, 1885). Platte's balloon with sails (*Z. f. L.*, 1883, p. 200), and many others.

There are still several supporters of these theories in spite of the failure of Wellner's sail balloon. They start from the consideration that a change in the position of the inclined plane in the fall of the flying apparatus ought to render a slow flight possible, and they have called it "wave flight." Their principal champion in literature was the engineer Platte (died 3rd Oct. 1903).

FIG. 112.—Rebenstein's navigable Montgolfiere folded so as to form a flying machine. V = rudder.

1852. Henry Giffard built a spindle-shaped air-ship in Paris (fig. 113). L = 44 m., D = 12 m., V = 2000 cb. m.. A rod, 20 m. long, was suspended 6 m. beneath the balloon. At a distance of 6 m. below this the car was hung. The car was furnished with two-winged propellers 3·5 m. in diameter, and a 3 H.P. steam-engine. Coke firing.

Triangular rudder sail between rod and balloon. Trial on 24th September 1852. Independent velocity 2 to 3 m. per second.

1855. *New Trials.*—L = 72 m., D = 10 m., V = 3200 cb. m. Instead of the rod, a stiffening, shaped to the curvature of the balloon spindle, was fixed to the upper part of the envelope, and the net was fastened to this. A light car framework, square shaped, was suspended from the four upper corners by the cords of the net. Rudder—a three-cornered sail on the body of the balloon. The air-ship lost its horizontal stability on landing and placed itself with a point upwards, and burst just above the ground, after the net and car-frame had previously slipped off. The passengers remained uninjured.

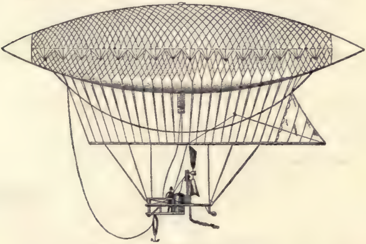


FIG. 113.—Giffard's air-ship.

Note.—The excitement in connection with the various trials gave rise to numerous projects with proposals of other forms of car suspensions, steering arrangements, motors, propellers, and working models. The following are worthy of mention :—

1853. Henry John Johnson. Patent No. 179 (Brewer-Alexander, *Aeronautics*). Spindle-shaped balloon; rigid car suspension; two pairs of screw oars arranged as turning wings, which, when revolving, drive at the same time an umbrella propeller; horizontal and vertical steering surfaces.

1859. Camille Vert in Paris. Model with small steam-engine (G. Tissandier, *La Navigation aérienne*. Paris, 1886).

1855. Lucien Fromage displayed, at the Paris Exhibition, the model of an air-ship which had a central tube to which the screw propellers were attached (L. Fromage, *Aérostat à tube central.* Rouen, 1889).

Note.—This and similar ideas occur frequently in later times : Finger, 1898; G. Cotta, 1901; Krocker, 1902.

1865. Paul Haenlein, English Patent No. 930, on a spindle-shaped balloon, with a horizontally placed frame about the middle axis. Screw propeller at the front, rudder aft. Rigid attachment to the car frame, which

1865. has a screw propeller under the bottom, for rising or sinking. Motor—a gas-engine of special construction. The heating material was taken from the balloon gas. An interior ballonet was filled with a corresponding amount of air in order to preserve the shape of the balloon.

Note.—An apparently similar scheme, but technically imperfect, was one by Smitter, first published in 1866 (G. Tissandier, *La navigation aérienne*). It had screw propellers moved by manual power.

1872. Paul Haenlein's air-ship (fig. 114), built in Vienna, was tried at Brünn, inflated with coal-gas. Balloon cylindrical, with conical points—L = 50·4 m., D = 9·2 m., V = 2408 cb. m. A small air-ballonet inside. Gas-engine, with 4 cylinders, of about 2·8 H.P. Weight per

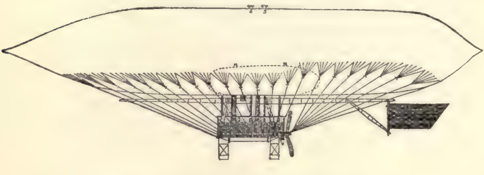


Fig. 114.—Haenlein's air-ship, 1872.

H.P., including the cooling water, 150 kg. On the framework, which was strongly attached to the balloon by means of a longitudinal stay, there were four-bladed screws, D = 4·6 m. The trapeze-shaped rudder was fastened to the stay.

The trials on 13/14 December 1872 gave an independent velocity of 1·3 m. per second, and proved the navigability. The screw made forty turns per minute. (*Bericht über das von einem Wiener Konsortium erbaute Luftschiff und die damit angestellten Versuche*, Vienna, 1873; *Z. f. L.*, 1882, pp. 46 and 79; *Der praktische Maschinen-Konstrukteur*, 1874, Nos. 1, 2, 3.)

Cordenon's proposal: egg-shaped balloon with strong central axis, to which the screw is attached in front, the rudder behind, and to which is fastened also the car. (*Il problema dell' aeronautica, soluzione dell Dott, P. Cordenons, Professor of Mathematics*, Padua, 1872;

Navigazione nell' aria, Milan, 1878, contains the same scheme in a more perfect form.)

1874. Paul Haenlein suggested that the body of the balloon should have the shape produced by the rotation of the keel line of a ship under water. This form would have the master section at a quarter of the length from the end, and gradually taper away from there (fig. 115).

Also: several cars each with a motor; the cars to be fastened under one another to a rigid framework attached to the longitudinal axis; rotary Kolben gas-engine, to prevent shaking or a gyratory motion—one which drives the air propeller and is driven by the gas *Der praktische Maschinen-Konstrukteur*, 1874, Nos. 23 and 24).

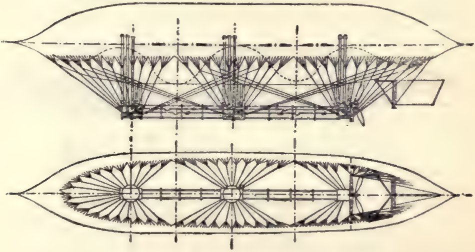


FIG. 115.—Haenlin's air-ship, 1874.

1881. Albert and Gaston Tissandier recommended the use of an electric motor. An air-ship model shown at the Electrical Exhibition in Paris.

1883. An air-ship, in which this principle was utilised, built and tested. Air-ship spindle shaped. L = 28 m., D = 9·2 m., V = 1060 cb. m. The construction was founded on the plans of Giffard and Dupuy de Lôme. The stiffening of the balloon lay at the height of the central axis on both sides, and consisted of wooden stays.

A Siemens electric motor with a bi-chromate battery.

Propeller, D = 2·85 m., made by Tatin.

1884/5. Renard and Krebs (fig. 116). Fusiform balloon similar to that proposed by Haenlein in 1874, master section at a quarter of the distance from the stem, 55·4 sq. m. Car 33 m. long, just under the balloon and

1884/5. rigidly attached to it by diagonal ropes. Two-bladed screw-propeller, D = 9 m., fixed in front. Rudder—a solid body, consisting of two four-sided pyramids lying with their bases on one another, placed behind between car and balloon. Net covering, air-ballonet, movable weight for balancing. V = 1864 cb. m., L = 50·42 m., D = 8·4 m.

9 H.P. Gramme electric motor. Chromium chloride batteries of a new design. (Capt. Renard, *Le ballon dirigeable "La France,"* Paris, 1886; *R. de l'A.*, 1889 and 1890.)

Trials.—Cf. Chapter IX., § 10. First successful trial on 9th August 1884. Maximum velocity attained, 6·5 m. per second. Good longitudinal stability. Variations 2° to 3° above and below the horizontal.

1885. In 1880 Debayeaux had propounded the theory that the

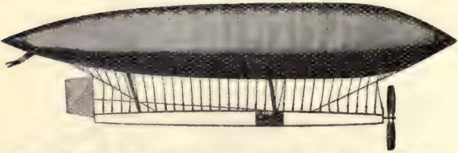


FIG. 116.—Renard and Krebs' airship "La France," 1884 (from an original drawing at Chalais-Meudon).

air in front of a balloon might be forced away by a mill-wheel, when the air-ship would be pressed forward into the artificially evacuated space.

A cylindrical-shaped balloon, with hemispherical ends, was built of gold-beater's skin in a balloon shed in Villeneuve St Georges. V = 3000 cb. m.; long car; 5 H.P. electric motor. The air-ship proved unstable in the trials, and the expected results were not obtained. (*Navigation Aérienne Système Debayeaux*, Paris, 1880; G. Tissandier, *La Navigation aérienne*, Paris, 1886.)

14 June. M. Wolf (in Berlin) attempted to fix an engine and propeller to a triangle which could be rotated placed in front of an air-ship, supported by the steam-pipe of its spirit steam-engine, which was fixed under the body of the balloon; V = 750 cb. m., L = 30 m., D = 8 m. at the hemispherical front end. No net nor rudder. The framework lacked rigidity, the envelope tore during the inflation, and the air-ship

failed to ascend (Moedebeck, *Handbuch der Luftschiffahrt*, Leipzig 1885).

1893. David Schwartz built a rigid aluminium air-ship in St Petersburg. On inflating, the interior cross stays broke, and made the framework unusable.

1886. Dr Woelfert of Berlin combined a cigar-shaped balloon with a Daimler benzine motor. L = 28 m., D = 8·5 m., V = about 800 cb. m. The car framework was of bamboo, and rigidly attached to the balloon, which had no net. A rigid rudder of Renard's pattern was attached. Twin-bladed aluminium screw, D = 2·5 m. 8 H.P. benzine motor. Ice-water cooling. A propeller for vertical movement was provided beneath the car.

Trials on 28th and 29th August 1896, 6th March and 14th June 1897. On account of the unsatisfactory results with the motor, Woelfert sought to improve it with a benzine vaporiser of his own pattern. The improvement was not a success, as was shown before the last trip by the flames springing out. The air-ship, owned by him and the showman Knabe, exploded in the air. Both aeronauts were killed. (*I. A. M.*, 1897.)

1895/7. David Schwartz built a rigid aluminium air-ship in Berlin (manufacturers, Weisspfennig and v. Watzesch). Balloon of elliptical cross-section; lengths of axes, 14 m. and 12 m.; 132 sq. m. cross-sectional area. Pointed in front, rounded off aft. Frame of car rigidly attached to body of balloon by lattice-work. The balloon was strongly braced internally, and had an outer covering of aluminium sheet 0·2 mm. thick. V = 3700 cb. m., L = 47·5 m. Aluminium car, with a 12 H.P. Daimler benzine motor working at 480 revolutions per minute. Benzine consumed, 0·42 kg. per H.P. hour. Under the central axis at each side there was an aluminium screw propeller, D = 2 m.; belts used to transmit power. No rudder, but a steering screw in the middle above the car, D = 2·75 m. Total weight of the air-ship, 3560 kg.

1897. 3 Nov. *Trial.*—Inflated by a method suggested by v. Sigsfeld, by pressing out air-filled fabric cells which were previously introduced into the balloon. Time taken, 3½ hours. On the day of the ascent there was a fresh E.S.E. wind of about 7·5 m. per second. The air-ship apparently made no headway against this, but remained stationary. During the voyage the driving belt fell from the screws, in consequence of the bending of the free hanging body. Afterwards the balloon was driven by the wind, but met with little damage on landing; but, after being emptied, was completely destroyed by the

1897. 3 Nov. pressure of the wind and the vandalism of the spectators. (*I. A. M.*, 1898; *Z. f. L.*, 1898.)

Note.—The proposal to employ metal envelopes arose from the search for an envelope which would be perfectly tight against the penetration of gas. Projects for aluminium air-ships were only not made earlier owing to undeveloped state of the aluminium industry. (*Micciollo-Picassi*, 1871.)

§ 5. REVIEW OF THE FAILURES AND PROGRESS IN THE NINETEENTH CENTURY.

The causes of non-success lay in the following circumstances:—

1. The laws relating to the air-resistance for different sizes and forms of surfaces were not sufficiently developed.
2. The power of the motors employed was over-estimated in comparison with the great head resistance to be overcome.
3. The action of the propeller in the air was not understood. The question as to whether a large slowly-rotating screw propeller, or a small rapidly-rotating one worked most satisfactorily, remained undecided. The driving power required for the various screw propellers was also not worked out.

The difficulties found have given rise to the following opinions as to the solution of the problem of flight.

1. Many workers on the subject wished to make use of the rise and fall of a balloon in combination with inclined planes. This idea exists only in theory at present.

2. Others conclude that the problem must be solved without the use of balloons. As supporters of the "heavier than air" principle, they oppose the adherents of the "lighter than air" principle.

This idea has met with little success up to the present, but we cannot speak with certainty as to what the future may bring forth. Progress became marked for the first time in the last quarter of the century; it was brought about by the requirements of war during the siege of Paris, 1870–71. The advancement may be traced to the following causes:—

1. Experiments at the cost of the State by the French Government (1872, Dupuy de Lôme; 1884–85, Renard-Krebs).

2. The organisation of military ballooning troops, who attacked the problem zealously, supported experiments,

1897. 3 Nov. and spread at the same time a proper knowledge of the subject of air-travelling in general, and stimulated meteorological science to investigate the conditions of the ocean of air by means of balloons.

3. The development of the technique of small motors, which itself marks out the various stages in the development of the air-ship—steam-engine, Giffard ; gas-engine, Haenlein ; electric motor, the brothers Tissandier ; benzine motor, Woelfert.

4. The discovery of the cheap mode of manufacture of aluminium and magnesium, and of the useful properties of different alloys of these metals.

5. The improvement of traffic generally, especially of automobiles, which, besides leading to the steady improvement in motors, produces a class of men educated in courage and rapid decisions, characteristics which an aeronaut *must* possess. Two nations have devoted themselves more than any others to the development of the air-ship—the French and the German, each in its own manner—so that it is necessary to-day to distinguish between a French and a German school in the art of airship building.

§ 6. THE TWENTIETH CENTURY.

1898–1900. Graf. F. von Zeppelin (manufacturers, Kober and Kübler, engineers) built a rigid air-ship in a floating balloon shed on the Lake of Constance, off Manzell near Friedrichschafen (fig. 117). It had the form of a prism of twenty-four surfaces with arch-shaped points. L = 128 m. ; D = 11·66 m. ; inner diameter, 11·3 m. ; V = 11,300 cb. m. Weight, including driving material (fuel) for ten hours (benzine, cooling water) and five men, 10,200 kg. Aluminium lattice-work construction with seventeen divisions, fifteen being 8 m. and two 4 m. long. Cross rings, with diagonal and chord braces of steel wire. The fabric envelope fitting the interior was filled with gas in seventeen hours. Fabric was also placed on the outside, and the space between automatically ventilated. Two aluminium cars (6·5 m. long, 1·8 m. broad, and 1 m. high) rigidly attached to the body of the balloon. To strengthen the whole a triangular aluminium keel of lattice-work was used, carrying a movable weight. The latest improvement consisted of a vertical rudder under the front portion, and a horizontal rudder, and in the rear a vertically standing

1898–1900.

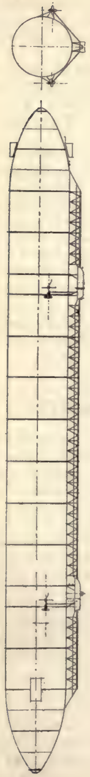


FIG. 117.—Graf v. Zeppelin's air-ship, 1904.

rudder. Each car was furnished with a 16 H.P. Daimler motor (giving 14·7 H.P. at 680 revolutions) with an electro-magnetic igniter. Weight of a motor and the necessary cooling water, 450 kg.; 6 kg. of benzine used hourly. Each motor drove two 4-bladed screw-propellers of aluminium sheet, 1·15 m. in thickness, placed at the centre of resistance on the side of the body of the balloon. Transmission by steel tubes with universal cross-joints and tension arrangements, in order that they might work even if the body of the balloon were deformed. Transmission of power by conical cog-wheels. Reversible driving arrangements in car, so that the air-ship could be driven backwards or forwards. For steering purposes the cars were provided with electric bells, telegraphs, and speaking tubes. The first two were polarised as a protection against fire.

Trials on 2nd July (Graf v. Zeppelin, v. Bassus, Burr, Wolf, Gross), 17th October, 21st October (in the two latter trials Lt. v. Krogh took the place of v. Bassus). Results—filling accomplished in a few hours, weighing, and getting away (Capt. v. Sigsfeld) without difficulty. Independent velocity attained, 7·6 m. per second. The numerous technical details of the air-ship stood the tests well — the stability was sufficient; the height of flight could be altered by travelling on an incline by means of the horizontal rudder; the landing on the water was free from danger.

The upper cross-stays were not strong enough for the long body of the balloon and bent some 28 cm. upwards when the air-ship was flying. This fault was corrected, as far as possible, after the first trial by altering the stay-ropes of the keel. The en-

1898–1900. velope of the balloon was not sufficiently gas-tight, and the motors required to be more powerful for the weight carried (*cf. I.A.M.*, 1899, 1900, 1901, 1902; K. v. Bassus, *Über den Graf. v. Zeppelin'sche Luftschiff. Bayrisches Industrie- und Gewerbeblatt*, 1901).

1898–1905. Santos-Dumont (manufacturer, Lachambre; fig. 118) made a series of trials with different models, continually improving them as the trials progressed. He succeeded with the last one in travelling from the "parc d'aérostation de l'aéroclub" round the Eiffel tower and back to the starting-point in 30 minutes 41 seconds, on 19th October 1902. The Deutsch prize of 100,000 frcs. was awarded to him. Up to 1905 Santos-Dumont had built in all fourteen different air-ships.

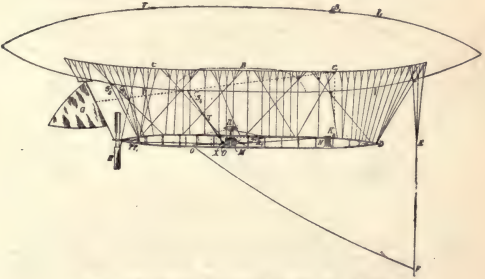


FIG. 118.—Santos-Dumont's air-ship No. 6, 1901.

Results.—All the experience of the French school from Giffard to Renard was made use of without excelling the labours of the latter with respect to the technique. Independent velocity about 7 m. per second, using a 16 H.P. Buchet motor in an air-ship of contents 622 cb. m. —D = 6 m., L = 33 m. (*I. A. M.*, 1902, p. 1; *Le génie civil*, 1902, Nos. 18–20; *L'Aérophile*, 1898–1902.)

Santos-Dumont is the founder of air-ship sport, and has made air-ship trials popular by his success. He has also lent considerable aid to the development and expansion of the air-ship industry in Paris.

Note.—The numerous air-ships which are being built at the present time represent no improvement in building technique, since the manufacturers have to take into account the ideas of

1898– 1905. their customers. The latter are, however, mostly amateur aeronauts who apply themselves to the subject on any kind of pretence—publicity, sport, or speculation. As far as we are concerned here, we need only consider those forms which offer something novel in construction or have brought out new scientific facts on their trials. On these grounds, many names which are known through advertisement or office will be omitted.

1900– 1901. Roze built a double air-ship in Colombo, but the trial was attended with mishap. He intended to do away with the rolling and pitching, and brought the engine, propeller, car, and parachute to the middle. He neglected to note that a small sectional area and a saving of weight are more important, and at the trial (5th and 6th September 1901) ascended only 15 m. and gave up the attempt (*L'Aérophile*, 1901, p. 146 ; *I. A. M.*, 1901).

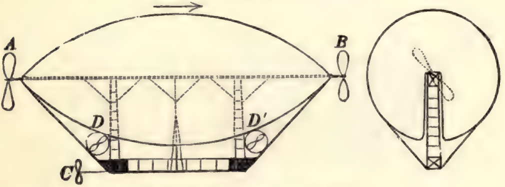


FIG. 119.—Severo's air-ship, 1902.

1901– 1902. Augusto Severo (manufacturer, Lachambre), a Brazilian, sought to bring the axis of the screw propeller into the axis of the balloon by a large bamboo frame, about which the spindle-shaped body of the balloon, provided with slits, was laid. L = 30 m., D = 12·4 m., V = 2334 cb. m. The car was placed in close proximity to the balloon (fig. 119). The balloon had two ballonets inside, each of $\frac{1}{10}$ the contents of the large balloon. In place of a rudder he attached screw propellers of 1·2 m. diameter to D and D′, in the front and rear of the car, but somewhat above it. For driving he had a propeller, B, which was intended to diminish the air resistance in front, and a driving propeller, A, these being worked by two Buchet motors, the front one of 12 H.P. and the one behind of 24 H.P.

1902. 12 May. *Trial.*—Severo dispensed with the propeller C, the air ballonets and the motor guards. His air-ship exploded fourteen minutes after the ascent from Paris. He and

1902. 12 May. his mechanic fell from a height of some 400 m. (*I. A. M.*, 1902, p. 113; 1903, p. 133; *L'Aérophile*, 1902, pp. 97 and 122).

Baron Bradsky-Laboun, secretary to the German Embassy in Paris, used a wooden stiffening (2) under the equator of his air-ship (fig. 120; manufacturer, Lachambre) for strengthening it, and fastened the rudder (8), consisting of a small elliptical-shaped area (3) (fig. 121), to it. To this wooden frame he fastened the car-holders (20 m. long), made of steel tubes, in the manner used in bridge building, the car being suspended by fifty steel wires of only 1 mm. diameter. The diagonal fastening was insufficient.

Dimensions:—Conical middle portion, 22 m. long. D in front, 6·35 m.; behind, 6·15 m. Points, arched in shape, 8 m. long in front, 4 m. long behind; V = 850 cb. m. No ballonet, but two cross walls at the ends of the central piece. A driving screw in the rear 4 m. in diameter, and a lifting screw under the car 2·5 m. diameter. 16 H.P. Buchet motor.

3 Oct. *Trial.*—Baron Bradsky, accompanied by his mechanic, Morin, drove with the wind over Paris. The rudder was not firmly enough attached to the driving screw, which transmitted power to the whole system. In attempting to land over Stains, the front part of the balloon, no longer tense, lifted, as Morin attempted to come to Bradsky, who was at the motor. The suspending wire broke in consequence of this, and both men fell to the ground with the car framework (*I. A. M.*, 1903, p. 1; *L'Aérophile*, 1902, p. 229).

3 Dec. The permanent International Aeronautical Commission in Paris resolved, on the proposition of Chevalier Pesce, an Italian member, in view of the accidents which had occurred, to publish a treatise on the nature of the dangers which are liable to occur, and on the means to prevent them, for the benefit of investigators (*I. A. M.*, 1903).

1902–1903. Lebaudy's air-ship (built by Julliot (engineer) and the aeronaut Surcouf) was of a new type. The balloon was cigar-shaped—L = 56·5 m., D = 9·8 m.; master section, 72 sq. m.; V = 2284 cb. m.—and was fastened to a rigid elliptical keel-shaped floor, 21·5 m. long, 6 m. broad, 102 sq. m. area, made of steel tubes. This, covered with shirting, would serve as a parachute in case of an accident, but was intended primarily to prevent the rolling and pitching during the voyage. A horizontal rudder, of 4·5 sq. m. area, was attached to the end of

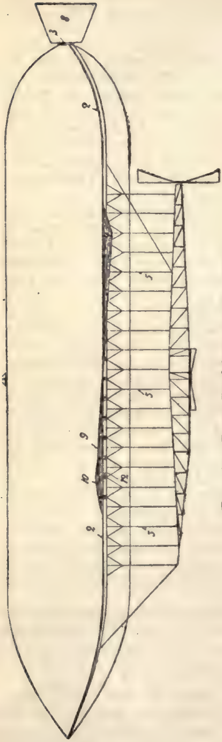


FIG. 120.—Baron Bradsky's air-ship, 1902.

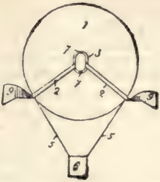


FIG. 121.

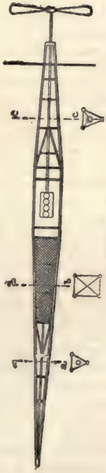


FIG. 122.

1902–1903. this floor surface, and some distance from this a vertical rudder 9 sq. m. in area.

The car, 4·80 m long, 1·60 m. broad, and 0·80 m. high, hung on twenty-four steel rods 5·6 to 6 mm. diameter, 5·8 m. under the floor surface. A rigid driving frame of steel tubing leads from the front portion to the floor above. A frame 1·4 m. high is placed under the car to catch it on landing.

A 35 H.P. Daimler-Mercedes motor, weighing 376 kg. without cooling water or firing material, is used to drive two twin-bladed screws each 2·8 m. in diameter, placed on either side of the car. Pull tested at 1056 revolutions, 160 kg.

Between the 25th October 1902 and the 21st November 1903, thirty-three experimental ascents were made with this model, the details of the construction being continually improved. The longest voyages were: 37 km. in 1 hour 36 minutes, 62 km. in 1 hour 41 minutes, 98 km. in 2 hours 46 minutes.

On 12th November 1903, the air-ship travelled from Moisson to Paris in a S.S.W. wind blowing 6 m. per second. Maximum height attained 300 m.

On 21st November 1903 the air-ship travelled from Paris to Chalais-Meudon at an average height of 150 m. in a W.N.W. wind of 6 to 8 m. per second. On landing, the balloon came into contact with a tree, tore, and burst.

1904. The Lebaudy air-ship was rebuilt (fig. 123). The balloon was rounded off elliptically aft. V = 2600 cb. m.; ballonet, 500 cb. m. Improvement in the stability by the addition of fixed and movable sails.

1904/5. Trial of the air-ship, thirty ascents being made. The Minister of War proposed that flights should be made from Moisson, over the camp at Chalons, and on to Verdun or Toul.

1905. Voyage from Moisson to Mieux. Distance, 91 km.
3 July. ,, Actual distance covered by air-ship, 95 km. Time, 2 hours 37 minutes.

4 July. ,, Miaux to Sept-Sorts. Distance direct, 12·7 km. Distance covered by air-ship, 17·5 km. Time, 47 minutes.

6 July. ,, Sept-Sorts to Mourmelon, near Chalons. Distance direct, 93·12 km.; covered by air-ship, 98 km. Time, 3 hours 21 minutes.

After landing, the balloon bumped, was torn by a tree, and burst.

1905. 8 Oct. Lebaudy's air-ship, rebuilt at Toul, commenced a series of military trials.

24 Oct. At the 65th trial M. Berteaux ascended in the Lebaudy air-ship, which is now to be introduced into the French army (*I. A. M.*, 1906, p. 124).

The Lebaudy air-ship has, so far, given the best results, and has clearly shown the way in which we may expect the air-ship to develop in the immediate future.

1905. Graf v. Zeppelin's air-ship rebuilt (engineer, Uhland), the size being nearly the same as before, the workmanship, however, being much superior.

Graf v. Zeppelin was able to rise from the surface of the water using only the vertical screw. Fore and aft the air-ship was furnished with similar screws, together giving a lift of 200 kg. An 80 H.P. Mercedes motor was provided in each car.

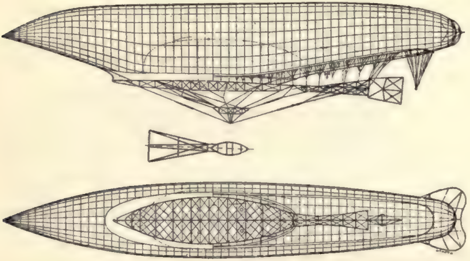


FIG. 123.—Lebaudy's air-ship, 1905.

30 Nov. Commencement of the trials with the completed air-ship (*I. A. M.*, 1905, No. 12).

1906. 17 Jan. At the trials Graf v. Zeppelin's air-ship showed evidence of being able to travel with a considerable independent velocity. Unfortunately, however, the longitudinal stability was poor, and one of the motors gave trouble. The landing was accomplished without shock, but the framework was subsequently damaged irreparably by a night storm, and further trials had to be abandoned. This air-ship was provided in the rear with a movable tail-surface (*I. A. M.*, 1906, p. 74).

26 May. Major v. Parseval experimented in Berlin with a new

1906. 26 May. air-ship having no rigid frame. L = 48 m.; D = 8·57 m.; V = 2300 cb. m. The car was 5 m. long, and hung 9 m. below the balloon. A Daimler motor was used, making 1000–1100 revs. per min. at full load. A four-bladed propeller, 4·2 m. in diameter, was used. The blades were of thin steel tubing covered with shirting. The passengers in the trial trip were Major v. Parseval, Captain v. Krogh, and Herren Müller and Keidel. The trial was most successful; the air-ship traversing several 8-shaped paths without difficulty. The trials are being continued, alterations and improvements being effected as the trials progress (*I. A. M.*, 1906, p. 96, Die Woche 1906, 9th June, "Der lenkbare Ballon Parseval," by A. v. Parseval).

1 Oct. Race for the Gordon-Bennett Trophy and several other valuable prizes. The competition was won by Mr Frank P. Lohn, an American competitor, who travelled the longest distance—from Paris to Whitby (England), about 400 miles—the time taken being twenty-four hours. The interest shown by the general public in the details of the race clearly shows the great interest now being displayed in matters affecting aerial navigation.

B.—POINTS TO BE NOTED IN BUILDING AIR-SHIPS.

§ 1. THE MOTOR.

The choice of a suitable motor is the first essential in building an air-ship, and of all the computations in connection with the air-ship, those necessary to deduce the power of the motor required are perhaps first in importance Every advance in the development of light motors corresponds to an advance in the development of the air-ship.

We must take into account the smallness of the weight for the greatest effective power, safe driving, and length of working time.

A comparison of the suitabilities of different motors can only be carried out if the effective power can be measured on the propeller screw-shaft, and if the weight of the gearing for the transmission of power, the fuel or driving materials, and the cooling water (for an hour's running) are taken into account. The effective power, measured conveniently by a brake-dynamometer, expressed in H.P., divided into the total weight

of the motor, gives the weight per H.P. Manufacturers' figures relating to their motors should never be taken as the basis of calculation by builders of air-ships. If the size of the air-ship is assumed, and the form is taken as similar to that of Renard's "La France," experiments with this air-ship gave the following formula connecting the minimum power (E) required for the production of an independent velocity v.

(1) $E = 0{\cdot}0415\ S\ v^3$ metre-kilograms per sec.

where S is the total effective area resisting the forward motion. If D is the diameter of the master section of the air-ship, then $S = \frac{\pi D^2}{4}$ (very nearly), and

(2) $E = 0{\cdot}0326\ D^2 v^3$ metre-kilograms per sec.

Example 1.—Let $S = 55{\cdot}4$ sq. m., $v = 6{\cdot}5$ m. per sec.

$$E = 0{\cdot}0415 \times 55{\cdot}4 \times 6{\cdot}5^3 = 631 \text{ m.-kg.}$$

Or in H.P. $N = \frac{E}{75} = \frac{631}{75} = 8{\cdot}5$ H.P.

Example 2.—Let $D = 11$ m., $v = 7$ m. per sec.

$$E = 0{\cdot}0326 \times 11^2 \times 7^3 = 1353 \text{ m.-kg. per sec.}$$
$$N = 18 \text{ H.P.}$$

It must be noted that this empirical formula is based on experiments (1885) in which the highest velocity attained was 6·5 m. per second, and that longitudinal vibrations of the air-ship will increase the effective area S, increasing the resistance of the air and causing greater power to be necessary to maintain the velocity.

According to Espitallier (*Le génie civil*, 1902, No. 19), the coefficient for the air-resistance in the case of Renard's air-ship, as determined by subsequent calculation, should be 0·0148 and not 0·01685 as given initially. Equation (2) should therefore read

(2*a*) $E = 0{\cdot}0267\ D^2 v^3$ m.-kg. per sec.

Setting this value in Example 2, we find a more favourable value for $N = 14{\cdot}7$ H.P.

§ 2. THE PROPELLER.

The choice of a suitable propeller is hardly of less importance, and can only be made after thorough tests in connection with the motor.

We may distinguish between the following forms of propellers: oars, revolving blade wheels, reaction propellers, and screws. The last named are the most suitable from the point

of view of the technique, and are usually employed (Chapter XV.). There are numerous forms of air-screw propellers. The tractive power of a screw depends on its form, size, and on the number of revolutions per minute made (angular velocity). Careful experiments must therefore be carried out in all these directions.

The tests may be best carried out by placing the propeller screw-shaft axially movable, or suspending it and attaching it to a dynamometer or a balance scale. Graf v. Zeppelin made comparison experiments with screws on an air-screw motor boat on the water. Both methods have their faults. They give us no conclusion respecting the expenditure of work, and the tractive power of propellers in motion with those velocities, which we wish to have when the air-ship is moving with the desired independent velocity. Experiments on this point may, perhaps, be made by a method proposed by Finsterwalder, which consists in mounting the propeller on a boat, and measuring the power with a dynamometer while dragging the boat through the water with a big velocity.

Probably they will give a smaller driving power by this method than we have hitherto been accustomed to assume in calculations, and a new standpoint for the construction of air-screws may be developed.

The results hitherto obtained, and assumed correct, may be summarised as follows:—

1. The square of the lifting power varies as the cube of the number of revolutions per minute.
2. The expenditure of work per unit time varies as the cube of the number of revolutions per minute.
3. The lifting power for a given expenditure of work varies inversely as the number of revolutions per minute. (G. Tissandier, *Les ballons dirigeables*, Paris, 1885. Ch. Renard, "Machine à essayer les hélices," *Rev. de l'Aér*, 1889, p. 93. Wellner, *Z. f. L.*, 1893; *Zeitschrift des österreichen Ingenieur und Arch. Vereins*, 1896, Nos. 35, 36. Jarolimek, *Z. f. L.*, 1894. W. G. Walker and Patrick Y. Alexander, *The Lifting Power of Air-propellers. Engineering*, 16/2/1900. *I. A. M.*, 1900, No. 3.)

§ 3. THE INDEPENDENT VELOCITY.

The motor and propeller, rigidly attached to a balloon of a form offering little resistance and having as small as possible longitudinal oscillations, determine the independent velocity of the air-ship, *i.e.* the absolute velocity which it would have in a dead calm. On the other hand, we call the velocity of

travel the relative velocity with which the air-ship moves with respect to the earth's surface.

The independent velocity of the air-ship, and the time it can be maintained, form the principal criterion for its practical usefulness. They can only be estimated beforehand very roughly on the basis of results known at the present time. Renard has given the following laws:—

The independent velocities of similar air-ships are proportional to the cube root of their tractive powers divided into the cross-section.

$$\text{(3)} \qquad \frac{v_1}{v} = \sqrt[3]{\frac{SA_1}{S_1A}}$$

where v and v_1 are the independent velocities in metres per second, S and S_1 the largest resisting surface of the air-ship in sq. m., and A and A_1 are the powers acting on the screw propeller shafts in H.P.

Example 3.—In the air-ship "La France" v was 6·5 m. per second:

$$S = 55{\cdot}4 \text{ sq. m.};$$
$$A = 8{\cdot}23 \text{ H.P.}$$

In Graf v. Zeppelin's air-ship:

$$S_1 = 103 \text{ sq. m.}$$
$$A_1 = 16{\cdot}4 \text{ H.P.} \quad (\textit{I. A. M.}, 1902.)$$

How large should v_1 be on the above supposition?

$$v_1 = 6{\cdot}5 \sqrt[3]{\frac{55{\cdot}4 \times 16{\cdot}4}{103 \times 8{\cdot}23}} = 6{\cdot}65 \text{ m. per second.}$$

As a matter of fact, the independent velocity of Zeppelin's air-ship was 7·8 m. per second. This number was deduced from the geometrical path traced out, after taking into account the direction and velocity of the wind as determined by means of a kite-balloon sent aloft at the same time.

The maximum attainable speed has not as yet been reached on account of various disturbances, and, according to Finsterwalder, Hergesell, and Müller-Breslau, should be about 9 m. per second. Although Renard's supposition is not perfectly correct, yet we may work with this less favourable formula until further results are to hand.

It may be pointed out that all Renard's formulæ refer to air-ships of the form of "La France," and their application to other forms cannot give more than approximate values.

§ 4. THE DIAMETER OF THE AIR-SHIP.

The weight, driving material (fuel), ballast, and useful load determine the size of the body of the balloon. This forms the

most important part of the air resistance in travelling, and it is imperative to choose the cross-section as small as practicable. It must, however, be large enough to have sufficient aerostatical power of manœuvring (*i.e.* upwards and downwards), and be able to attain the desired height by the use of ballast (throwing out a weight = 1 per cent. of the total weight of the air-ship will cause an alteration in height of 80 m.; *cf.* Chapter VI., § 3). Since the shape must be a long figure in all circumstances, we can determine the diameter as soon as we know the driving power E of the motor (in kilograms), on the basis of the desired independent velocity.

From Renard's formula (2) we can deduce

$$D = \sqrt{\frac{E}{0 \cdot 0326 v^3}}. \tag{4}$$

Example 4.—Let $E = 16 \cdot 4$ H.P. $= 1230$ m.-kg. per sec.
$v = 7$ m. per second.

Then $$D = \sqrt{\frac{1230}{0 \cdot 0326 \times 7^3}} = \frac{1230}{11 \cdot 18} = 10 \cdot 5 \text{ metres.}$$

§ 5. THE SHAPE AND SIZE OF THE BALLOON.

The most favourable shape is that which offers the least head and side resistance, while possessing the greatest volume and the greatest longitudinal stability.

In most forms of balloons for air-ships we can distinguish between three parts—the forward point, the long middle portion, and the rear part. The middle portion forms the principal carrier of the total weight; its prolongation is limited only by considerations regarding the preservation of shape and its stability. It is advisable to consider this middle portion alone in calculating the size of the carrying body, and to leave the end portions out of account. The form is either cylindrical, tun-shaped, or half tun-shaped (blunted spherical-cone shaped). Underneath, the shape is flattened out. The points and ends are usually attached tangentially to this middle body, in such a manner that the curve, from which the form of the balloon may be derived by a revolution about its axis, will be a regular line with parabolic ends.

Haenlein proposed to use the keel line lying under water of a sea-ship, Renard, two parabolic curves of different focal lengths, for the air-ship curve. Both give unsymmetrical bodies of rotation whose greatest cross-section lies in the first quarter of the longitudinal axis. This form does not admit the possibility of

bringing the propeller in front at the blunted portion near to the centre of pressure and the central point of the driving force. Renard's parabolas were determined as follows :—

The point: $$x=r\left(1-\frac{y^2}{(3r)^2}\right);$$

the middle portion and the end: $$x=r\left(1-\frac{y^4}{(9r)^4}\right).$$

The favourable properties of the form as regards overcoming the resistance were proved empirically by experiments in water.

Such experiments ought, however, to be made in the air itself.

Ahlborm (*I. A. M.*, 1904, No. 6) has proved that the formation of eddies at the sides and behind the moving balloon have an important influence on the air-resistance and the stability.

§ 6. CALCULATION OF THE DIMENSIONS.

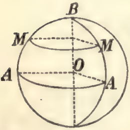


FIG. 124.—Construction of a spherical cone (spindle).

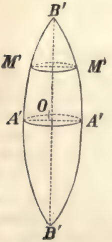


FIG. 125 — A spindle.

Assuming that the diameter of the master cross-section and the probable total weight are given, the dimensions may be calculated with the aid of the following formulæ.

I. Cylinder.

(5) Area of envelope: $O=2\pi rh$.

(6) Contents: $V=\pi r^2 h$.

II. Spherical cone and blunted cone (after Voyer).—The spherical cone may be looked upon as a portion of the surface of a sphere, B A B A, which is rolled up, so that the two semicircles, B A B, overlap (fig. 124). If the section is bounded by two arcs reaching from pole to pole, on rolling together we get the spindle form (fig. 125).

Let R = the radius of the original sphere;
r = ,, ,, spherical cone;

$$K=\frac{r}{R}.$$

a = longitude of a parallel circle M M of the original sphere, corresponding to M′M′ on the spherical cone.

Further, let $\sin\theta=K=\frac{r}{R}$. θ is the semi-angle at the apex of the spherical cone.

A. *The mean cross-sectional area of the spherical cone* (figs. 126 and 127).

Determination of the position of the point M.

We have $\quad \text{arc } A'M' = \text{arc } AM = R\alpha.$

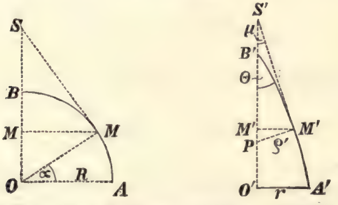
Abscissa : $\quad x = r \cos \alpha.$

Ordinate : $$y = \int_0^\alpha d\alpha \sqrt{R^2 - r^2 \sin^2 \alpha}.$$

Tangent M'S' (μ is the angle made by the tangent with the axis O'B').

$$\sin \mu = K \sin \alpha.$$
$$M'S' = MS.$$

Radius of curvature ρ at M' $\left(\rho' = \frac{x}{\cos \mu} = M'P\right)$; $\rho = \frac{R^2}{\rho'}$.



FIGS. 126 and 127.—Figures for calculation of spindle form.

Pole B_1 : semi-angle at the apex

$$\theta = \sin^{-1} K.$$

Surface : (1) Portion A'M' M'A' (fig. 125),

$$\sigma = R^2(\mu + \sin \mu \cos \mu) ;$$

(2) Portion A'B'A',

$$\Sigma = R^2\theta + rb,$$

where $$b = \sqrt{R^2 - r^2}.$$

B. *Spherical cone* (*blunted*) A'M' M'A'.

(7) Surface : $\quad O = 2\pi K R^2 \sin \alpha.$

(8) Length : $\quad L = RE$

where $$E = \int_0^\alpha d\alpha \sqrt{1 - K^2 \sin^2 \alpha}.$$

(9) Contents:

$$V=\frac{\pi R^3}{3}\left[K^2 \sin\alpha\cos\alpha\sqrt{1-K^2\sin\alpha}+(1+K^2)E-(1-K^2)F\right]$$

where $$F=\int_0^\alpha \frac{d\alpha}{\sqrt{1-K^2\sin^2\alpha}}.$$

C. *Spherical cone* A′B′A′.

(10) Surface: $O=2\pi KR^2$,

or $O=2\pi rR$.

(11) Length: $L=RE_1$

where $$E_1=\int_0^{\frac{\pi}{2}} d\alpha\sqrt{1-K^2\sin^2\alpha}.$$

(12) Contents: $$V=\frac{\pi R^3}{3}\left[(1+K^2)E_1-(1-K^2)F_1\right]$$

where $$F_1=\int_0^{\frac{\pi}{2}} \frac{d\alpha}{\sqrt{1-K^2\sin^2\alpha}}.$$

(*Cf.* Voyer, "Les cones sphériques et leur application à la construction des ballons allongés," *Rev. de l'Aér*, 1894.)

With the help of Legendre's tables of elliptical functions (see Table XXI.), which give us $\theta=\sin^{-1} K$ (*i.e.* the semi-angle at the apex of the spherical cone), as well as the values of E_1 and F_1 for different values of K, we can determine easily and rapidly all the constants of the bodies of balloons which are formed from curves of spherical cones.

Example 5.—**Cylindrical form.**

Let $D=2r=10{\cdot}5$ m., $L=120$ m. Then, according to the formula (5):

$$O=10{\cdot}5\times\pi\times 120=3958 \text{ sq. m.}$$
$$V=(5{\cdot}25)^2\times\pi\times 120=9922 \text{ cb. m.}$$

Example 6.—**Spherical cone.**

Let $R=42$ m., $r=5{\cdot}25$ m., then $K=\frac{r}{R}=\frac{1}{8}$.

According to formula (10):

$$O=2\pi\times 5{\cdot}25\times 42=1354 \text{ sq. m.}$$

According to formula (11):

$$L=42\ E_1.$$

Since $K = \frac{1}{8} = 0{\cdot}1250$, Table XXI. gives θ, the semi-vertical angle of the cone, a value between 7° ($0{\cdot}1219$) and 8° ($0{\cdot}1392$). By interpolation we get, approximately, $\theta = 7^\circ\ 10'$.

For 7° $E_1 = 1{\cdot}5649$, according to Table XXI.; and for 8° $E_1 = 1{\cdot}5632$.

For $7^\circ\ 10'$ by interpolation, $E_1 = 1{\cdot}5646$,
whence $L = 42 \times 1{\cdot}5646 = 65{\cdot}7$ m.

The contents may be found by substituting the above values in formula (12):

$$V = \frac{\pi 42^3}{3}\left[\left(1 + \left(\frac{1}{8}\right)^2\right).\quad 1{\cdot}5646 - \left(1 - \left(\frac{1}{8}\right)\right)1{\cdot}5770\right].$$

Where F_1 is determined from interpolation between the two values $1{\cdot}5767$ and $1{\cdot}5785$:

$$V = \frac{3{\cdot}1415 \times 42^3 \times 0{\cdot}042}{3} = 3258 \text{ cb. m.}$$

Example 7.—If L and r are given and we wish to find O and V, we must first find E_1 and the fraction K, in order to be able to apply Table XXI.

Let $L = 3r$; $r = 5{\cdot}5$ m.
Formula (11) gives $L = RE_1$,
or $3r = RE_1$;

$$\frac{3r}{R} = E_1 \quad \text{or} \quad E_1 = 3K.$$

The tables show that for

$$\theta = 29^\circ \begin{cases} K = 0{\cdot}4848 \\ 3K = 1{\cdot}4544 \text{ and } E = 1{\cdot}4740\,; \end{cases}$$

and for

$$\theta = 30^\circ \begin{cases} K = 0{\cdot}5000 \\ 3K = 1{\cdot}500 \text{ and } E_1 = 7{\cdot}4675. \end{cases}$$

For 29° $E_1 - 3K = 1{\cdot}4740 - 1{\cdot}4544 = +0{\cdot}0196$;
and for 30° $E_1 - 3K = 1{\cdot}4675 - 1{\cdot}5000 = -0{\cdot}0325$.
For 1° alteration of θ, $E_1 - 3K$ alters $0{\cdot}0521$.

Whence one must alter θ by $\frac{196}{521}$ of 1° in order that $E - 3K = O$;

$$\theta = 29^\circ + \frac{196}{521} \text{ of } 1^\circ = 29^\circ{\cdot}376 = 29^\circ\ 22'{\cdot}56.$$

§ 7. THE CONSTRUCTION OF SPHERICAL CONES.

1. **Out of longitudinal strips.**—As many strips are taken from the sphere, out of which the spherical cone is imagined

to be formed, as are included by the spherical triangle on the surface of the sphere (see Calculation—Chapter IV., § 9).

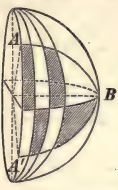


FIG. 128. — Construction of transverse strips for spindle balloons.

2. **Out of transverse strips** (K < $\frac{1}{2}$).—Imagine the surface of the sphere to be divided by meridians equal in breadth at the equator to the width of the material, and imagine the spherical cone developed as a spherical triangle on this sphere, the central line of the triangle coinciding with the equator of the sphere, then the portions of the meridian lines falling within this spherical triangle A B A′ give the exact cuts for the patterns of the different transverse gores (fig. 128).

§ 8. THE MAINTENANCE OF THE SHAPE.

A choice lies open between a soft form maintained by an interior excess pressure and a form stiffened by a framework.

The first may be obtained by keeping up the pressure in one or more small air-balloons, introduced into the gas-balloon, by means of fans, which must be kept constantly running by a motor (French school); or by a method also

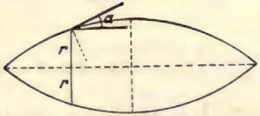


FIG. 129.—Determination of the pressures inside an air-ship.

suggested by Meusnier, of surrounding the gas-balloon by an air-balloon in which the pressure is similarly maintained by fans.

The interior pressure, p, must have a certain value to keep the balloon stiff. It may be determined in kilograms per sq. m. by the following method (due to Finsterwalder).

If the moment of the acting forces (fig. 129; weight acting downwards, buoyancy upwards) with respect to the highest point of any circular cross-section of radius r (m.) = M (kg.-m.), then, to prevent a diminution in the cross-section:

(13) $\pi r^2 p \,.\, r = \mathrm{M}$ or $p = \frac{\mathrm{M}}{\pi r^3} \left(\frac{\text{kg.}}{\text{m}^2.}\right)$.

The assumption is made that the distribution of pressure in the interior is uniform; p = pressure at the equator of the balloon (not at upper end of cross-section). The girth must be able to maintain at least a pressure of $\pi r^2 p$ kg. everywhere, and the envelope at least a tension

$$S = \frac{\pi r^2 p}{2\pi r \cos \alpha} = \frac{rp}{2 \cos \alpha}\left(\frac{\text{kg.}}{\text{m.}}\right) \tag{14}$$

where α is the angle subtended between the tangent to the meridian and the axis of rotation.

From the first formula for M we see that the resistance against deformation is small at the ends; and from the latter, that the material is most tightly stretched at its greatest cross-section.

The maintenance of shape may be more simply attained automatically by the German Parseval-Sigsfeld system (see Kite

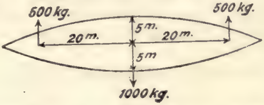


FIG. 130.—Example of the preservation of shape by the interior pressure when the load is suspended under the centre.

Balloon—Chapter IV., § 25) by means of the pressure of the air opposing the flight.

In this case, however, difficulties in connection with the preservation of the shape arise as soon as the forward motion ceases, or when, as on landing, the balloon must be worked backwards.

The tension is, on the average, more than double as great in the longitudinal axis.

If the circumference is n (m.) and the area F (sq. m.), then the tension is greater than

$$S = \frac{Fp}{n}.$$

Example 8 (fig. 130).—A spindle-shaped balloon of length 60 m., diameter 10 m., and lifting power 1000 kg., carries its load principally on the circular middle cross-section where $\alpha = 0$. The lifting force of 500 kg. in each half acts as though passing through a point 20 m. distant from the central cross-section. Further, $M = 500 \times 20 = 10{,}000$ m.-kg. In order that the balloon may not collapse, we find from the above formulæ that the

interior pressure, p, must $= \dfrac{10,000}{125 \times 3{\cdot}14} = 25{\cdot}5 \ \dfrac{\text{kg.}}{\text{m.}^2}$, or a pressure of 25 mm. of water.

The girth on the bulging side must be able to stand a tension of $25 \times 3{\cdot}14 \times 25{\cdot}5 = 2000$ kg., and the material of $\dfrac{5 \times 25{\cdot}5}{2 \times \cos 0}$ $= 63{\cdot}8 \ \dfrac{\text{kg.}}{\text{m.}}$.

These are minimum numbers. At right angles to the axis the material must be able to bear a greater stress. If the circumference of the master section is 150 m., and its area 800 sq. m., then with a mean pressure of $25{\cdot}5 \ \dfrac{\text{kg.}}{\text{m.}^2}$ on the whole section the total force is $800 \times 25{\cdot}5$ kg., which must be borne by the circumference of 150 m.—*i.e.*, on an average, 130 kg. per metre.

Example 9.—Assume the car suspensions distribute the weight of 1000 kg. on the two halves, as indicated in fig. 131.

Then the moment with respect to the uppermost point of the central section is:

$$M = 850 \times 20 - 500 \times 20 = 7000 \ \frac{\text{kg.}}{\text{m.}^2},$$

whence

$$p = \frac{7000}{125 \times 3{\cdot}14} = 17{\cdot}8 \ \frac{\text{kg.}}{\text{m.}}.$$

The upper girth must stand

$$25 \times 3{\cdot}14 \times 17{\cdot}8 = 1400 \text{ kg.},$$

and the material (in the middle)

$$S = \frac{5 \times 17{\cdot}8}{2 \times \cos 0^\circ} = 44{\cdot}5 \ \frac{\text{kg.}}{\text{m.}}.$$

If it will not stand this, then the balloon falls together with the points downwards. The mean tension in the maximum section at right angles to the longitudinal axis is $95 \ \dfrac{\text{kg.}}{\text{m.}}$, calculated as in Example 8.

We learn from this how greatly the method of suspending the car affects the tensions in the material, and how necessary it is to choose a good method of suspension, or to use a rigid keel, in order to diminish the moment M. The pliable shapes have the advantage of lightness, and can therefore be used conveniently for small air-ships; they permit a landing to be made also, after the manner of free balloons, without special arrangements. On the other hand, they are of little use for big velocities or large air-ships; the material would require to be

very heavy, the construction would be difficult, and the maintenance of longitudinal stability very uncertain.

For large air-ships a rigid form, stiffened by cross stays (new German school), is not only more convenient, but is, in fact, a *conditio sine qua non.* It renders safer the rigid connection of every part, assuming that it has the requisite strength, and simplifies the introduction of i m m o v a b l e cell-systems, which is of fundamental importance for the maintenance of longitudinal stability. The propeller also can be attached directly to the body of the balloon. A more certain protection of the envelope of the gas-balloon against the pressure of the wind, radiation of the sun, and influences of the weather, by means of an outer protecting envelope, can be easily made.

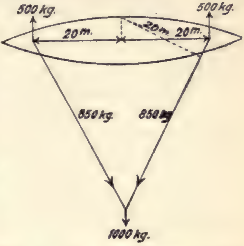


FIG. 131.—Example of the preservation of shape by the interior pressure when the load is divided between the two halves of the balloon.

Lastly, such an air-ship can be combined with aviatic means of flight (kite surfaces), giving thus a natural transformation to purely aerodynamic air-ship voyaging in which, in the eyes of many aeronauts, the hope of the future lies.

The points are usually shaped as spherical cones. The resistance offered by the air depends on the shape of the pointed end. The reduction of the air resistance has been compared to that offered by a plane surface moved against the air, and several coefficients found, which have been derived from empirical trials (*cf.* Chapter XIII.).

§ 9. THE STABILITY.

The maintenance of stability in long air-ships in a horizontal position in the air is one of the most difficult problems for the constructor.

Movements of the longitudinal axis (pitching) are unavoidable. They arise from irregularities in the direction of the resistance owing to the changing wind, to ascending and descending air-currents, from the irregular period of the motor, from unequal loss of gas in different cells and the compensation which must be made by throwing out ballast, and, lastly, from movements of weights longitudinally.

Having regard to these different sources of disturbance, the centre of gravity of the whole system should lie as low as possible beneath the centre of resistance It is also advantageous to have the point of application of the driving propeller as nearly as possible at the height of the centre of resistance, in order to prevent any turning moment between driving force and resistance.

In the distribution of weight along the axis, account must be taken of the distribution of the lifting forces. The load is made up of the independent weight and the useful load together. While the independent weight lies immovable, the useful weight may be altered and moved about. With a rigid framework, these alterations do not matter if only both halves of the length are kept in equilibrium. For movements to one side, equilibrium may be conveniently maintained by a movable weight or by a horizontal rudder (kite surface).

The safety of the construction makes some calculations on the time of swing, and angle of tilt of the axis for movement of weight, necessary.

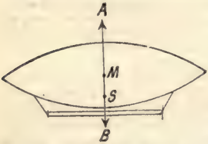


FIG. 132.—Calculation of the time of swing of an air-ship.

1. Calculation of the time of swing and the angle of tilt (Finsterwalder).

Two systems of forces act on the air-ship—the weight of each portion with the point of application of the resultant at the centre of gravity, S (fig. 132), and the buoyancy whose resultant passes through the centre of gravity, M, of the gas.

For stable equilibrium, M must lie higher than S. Let $MS = a$ (m.). The two principal vibrations of the air-ship, about the axis (rolling) and about a perpendicular to the axis (pitching), occur about axes through the point M. If Q is the moment of inertia of the air-ship (when not filled with gas) about the particular axis, and P (kg.) its weight, then the corresponding time of swing is :

$$(15) \qquad T = 2\pi \sqrt{\frac{Q}{Pa}} \text{ seconds.}$$

Example 10.—Rolling of Zeppelin's air-ship.

Of the 12,000 kg. total weight, about 8000 kg. (framework, envelope, and ballast) was situated at a distance of 5·5 m. from the axis of the cylinder, on which the point M lay, when the balloon was tightly inflated. Its share of Q is

$$80,000 \times 5{\cdot}5^2 = 242,000 \text{ kg.-m.}^2$$

The remainder is 8 m. distance, and gives

$$4000 \times 8^2 = 256{,}000 \text{ kg.-m.}^2 ;$$

whence
$$Q = \frac{498{,}000}{g},$$

where g is the acceleration of gravity $= 9{\cdot}81$ m. per second.

$$T = 2\pi \sqrt{\frac{498{,}000}{36{,}000 \times g}} = 6{\cdot}28 \sqrt{\frac{498}{360}} = 7{\cdot}4 \text{ seconds.}$$

For the pitching, the moment of inertia of the gas in the cells, and the damping of the swings by the resistance of the air, must be taken into account. The latter is very complicated when the air-ship is actually travelling.

2. Calculation of the angle of tilt (Hergesell).

Let A B (fig. 133) be the horizontal and C D the vertical axis

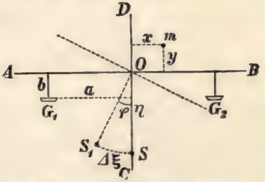


FIG. 133.—Calculation of the tilt of an air-ship.

of symmetry of the air-ship before the movement of the weight; G_1 and G_2 the positions of the cars at distances a and b from the axis of symmetry.

S = centre of gravity; S_1 = new position of centre of gravity after moving a weight p from the car G_1 to G_2.

Let the co-ordinates of S be

$$\eta = SO, \ \xi = 0.$$

Let m be any small portion of the air-ship with the co-ordinates (x, y) with respect to A B and C D; Σ denote a sum relating to all portions of the air-ship; then ξ and η are determined by the equations

$$M\xi = \Sigma mx = 0,$$
$$M\eta = \Sigma my,$$

M being the total weight of the air-ship.

The sum may be divided into two portions—the first portion

consisting of all particles of the air-ship with the exception of the movable weight p; this forms the second portion, and has the co-ordinates a and b.

$$\xi = \Sigma_1 mx + ap = 0,$$
$$\eta = \Sigma_1 my + bp.$$

When the weight p is moved from G_1 to G_2, ξ is no longer zero but $= \Delta\xi$; a becomes $-a$.

We get $\quad M\Delta\xi = \Sigma_1 mx - ap$;

but if we subtract $\quad 0 = \Sigma_1 mx + ap$, we get

$$\Delta\xi = \frac{2ap}{M}.$$

The angle ϕ, through which the air-ship tilts, is given by

$$\tan\phi = \frac{\Delta\xi}{\eta} = \frac{2ap}{\eta M}. \tag{16}$$

Example 11.—Let $a = 30$ m., $p = 75$ kg., $M = 10{,}200$ kg., $\eta = 3$ m.

Then $\quad \tan\phi = \frac{2 \times 30 \times 75}{3 \times 10{,}200} = 0{\cdot}14705$,

whence $\quad \phi = 8° \; 20'$.

The gas in the interior of the balloon must be prevented from surging to and fro. The best protection against this is the cell system, both with free and rigid balloon envelopes. In the former case, where the balloon must be kept tight by an inner balloon, a disturbance in the stability, owing to the gas flowing to the highest point, can easily occur if the fans fail to act during the descent, which, if the cell system is not used, may lead to the bursting of the balloon. (Giffard, 1853; Santos-Dumont, 1901, 1902.)

Horizontal rudder surfaces are of great use in preventing disturbances of stability. They have proved their value in the experiments carried out by Graf v. Zeppelin. Lifting screws, requiring power, are not to be recommended.

§ 10. THE STRENGTH OF THE FRAMEWORK.

The framework is strained by the pitching of the vessel. The greatest strain lies in the vertical plane of the longitudinal axis. The difficulties arise from the fact that the load (car, ballast, etc.) is concentrated at single points, while the buoyancy is distributed equally along the whole length of the axis. The bending moment caused by this must be resisted by the material of the framework. As great care as possible must therefore be taken

to divide the load equally, though the distribution is unsatisfactory even when several small benzine-motors are used, or an electric motor and batteries of accumulators are employed.

In travelling through the air, there is a horizontal strain due to the action of the air-resistance in front and to the reaction of the propeller.

Changing the direction of flight causes a bending strain, in a horizontal sense, in consequence of the placing of the rudder.

Torsional strains, which may arise if anyone climbs outside on the framework, or if the weights are not distributed in a vertical plane, have no important significance.

Finally, we must allow for the strain when the air-ship strikes water or land. This depends essentially on the velocity of descent, on the weight carried, and on the angle at which impact is made. It is impossible to compute.

The construction follows from the theory of structures. The moment of inertia, and the resisting moment of the profile, must first be determined.

§ 11. STEERING.

The rudder must be made of rigid surfaces ; free sails must not be used. Wooden or light metal frameworks have proved very suitable, covered with balloon shirting. The rudder must be rigidly fastened to the body of the balloon on firm pivots ; it must be easily managed by ropes from the car. Results showing the best size and arrangement of rudder are at present wanting.

§ 12. THE CAR.

When unstiffened envelopes are used, a long car serves to stiffen the whole and to distribute the weight on the envelope. It is fastened as firmly as possible to the body of the balloon either by a tube or lattice-work frame, or by a rope suspension. The car is made of bamboo, wood, light metals, balloon shirting, steel and copper wire.

In rigid air-ships with a metal framework the cars have hitherto been made of aluminium alloys and nickel steel, and have proved excellently adapted for the purpose, especially for landing on water.

C.—TRAVELLING BY AIR-SHIP.

§ 1. MISCONCEPTIONS REGARDING AIR-SHIPS.

The view is held quite generally that an air-ship may perhaps travel in a calm, but can never travel against a wind.

A balloon floating in uniformly moving air floats along in it, and the passengers feel no trace of wind as long as this is the case. The wind is first felt if, by aerostatical means (throwing out ballast, allowing gas to escape), the balloon is caused to rise or fall, or if a horizontal movement of the balloon is brought about by dynamical means.

In actual travelling, it is thus obvious that the direction of the wind is quite a secondary question. The resistance of the air will only be noticeable by the aeronaut on that side which is moving against the surrounding air, quite independently of the direction in which this air may be moving with respect to the earth—at all events, as long as it is uniform within the dimensions of the air-ship.

The aeronaut has only to encounter a wind pressure from the fore, under all circumstances, as long as he travels with the point of the air-ship forwards.

§ 2. TRAVELLING TO A FIXED PLACE.

The route with respect to the earth must be calculated, allowing for the deviation in the path due to the wind ; whether or no an air-ship will be able to reach a fixed distant place or not depends essentially on the relation of its independent velocity to the velocity of the wind, and on the length of time which the air-ship motor will run.

In a calm, all geographical points lying within the circle of action of the air-ship may be reached. In a wind, however, we must distinguish between the following three cases which determine the region which the air-ship can cover.

1. The independent velocity is less than the velocity of the wind.
2. The independent velocity is equal to that of the wind.
3. The independent velocity is greater than the velocity of the wind.

§ 3. THE INDEPENDENT VELOCITY IS LESS THAN THE VELOCITY OF THE WIND.

Let $CB = v =$ independent velocity of the air-ship in metres per second ; $AB = w =$ velocity of the wind in the same units ; $A =$ starting-point (fig. 134).

Imagine the air-ship working dead against the wind, then it will be driven back a distance $= v - w$ every second. If, on the contrary, it travels with the wind, it moves $v + w$ metres every second.

According as it is directed against or with the wind it will reach the point C or C′ respectively.

If we describe a circle with radius $v = \text{C B}$ about B as centre, then this circle includes all points which the air-ship can reach in unit time from the starting-point under the given conditions.

In order to reach the points C″ or C‴ on this circle, the keel line $a\,b$ of the air-ship must be kept at an angle C″B A or C‴ B A to A B respectively.

From this it follows that even in stronger winds than the

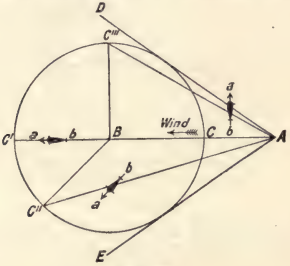


FIG. 134.

independent velocity of the air-ship points lying within the angle D A E can be reached from the point A. D A E may be called the *angle of action* of the air-ship with the wind w. The surface which is commanded in this angle during the voyage may be called the *sector of action*: its area depends on the length of time which the motors of the air-ship will run.

4. THE INDEPENDENT VELOCITY IS EQUAL TO THE WIND VELOCITY.

If $v = w = \text{A B}$, then the air-ship commands an angle of 180°. Its velocity, with respect to the earth, may lie between 0 and $v + w$ metres per second. If the air-ship is at A and is worked against the wind ($w = \text{AB}$), then it may be driven towards either D or E, according to the direction of the rudder (fig. 135).

If it is desired to reach the point C′, it must direct its course at full speed towards C′ from A by B.

In order to reach the point C″ it must direct its course so as to make an angle A B C″ with the direction of the wind. If the

circle about A C′ as diameter includes all points attainable in the first hour, then the circle with centre C′ and radius C′A includes

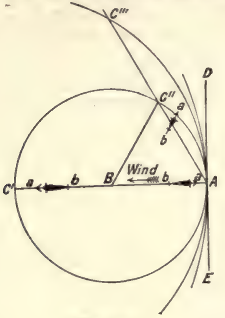


FIG. 135.

all points attainable in the second hour. We can therefore travel from C″ outward towards C‴ by keeping the keel line parallel to B C″.

§ 5. THE INDEPENDENT VELOCITY IS GREATER THAN THE WIND VELOCITY.

When $v > w$, the air-ship commands a field of 360° and can

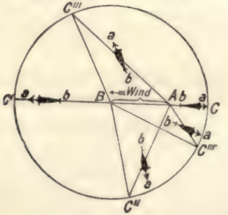


FIG. 136.

reach any desired point. If A (fig. 136) is the starting-point,

B C the path that it would cover in an hour by means of its own velocity, A B the distance covered by the wind in the same time, then the circle with B C as radius described about B includes the geometrical position of all places which can be attained by the air-ship in the first hour. Its velocity varies between $v - w$ and $v + w$ metres per second.

§ 6. AERONAUTICAL NAVIGATION.

A particular system of aeronautical navigation has not as yet been put into practice, as none of the air-ships hitherto built have gone beyond the trial stages. We can therefore, in what follows, only give a general idea of the manner in which the navigation of the air-ship must be developed, the navigation not being essentially different from that of sea-going ships. Charts, a compass, and an air log are, of course, necessary for the geographical navigation; also a plumb-line, as long as the earth is visible; while a chronometer, sextant, and azimuth compass must be used as soon as the air-ship is well above the clouds, and at night for astronomical navigation.

A.—GEOGRAPHICAL NAVIGATION.

From §§ 3–5 it follows that in the first place we must determine the angle which the keel line of the air-ship must make with the point aimed at. In the voyage this angle, determined with respect to the direction of the wind, must be used in connection with the compass needle. If we join the starting-point A with the point aimed for, C on the chart, we determine by the angle β the position of the keel line. In triangle A B C we know A B $= w$, B C $= v$, and angle C A B $= \alpha$ (fig. 137). Whence we obtain

$$\sin \beta = \frac{w}{v} \sin \alpha.$$

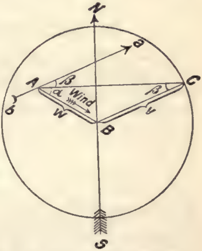


FIG. 137.—Geographical navigation.

Now, since the angle which the line A C makes with the compass needle is known, we know also the angle which the course of the air-ship must make with the needle in order to attain the point C.

The relative velocity of the air-ship with respect to the

earth's surface may be practically determined by viewing two points at a known distance apart on the earth's surface, which lie in the course, and determining the time taken to pass between them by means of a chronometer or by a method due to Renard using an air-log.

The latter consists of a small gold-beater's skin balloon, 60 cm. in diameter, filled with hydrogen, which is attached to a silk thread 100 m. long on a reel. The co-efficient of friction (k) of this air-log must be determined beforehand. The relative velocity (v') may be obtained with sufficient accuracy for practical purposes if we determine exactly the time (t) required for the full 100 m. to unwrap. Then

$$v' = \frac{100}{t} + k \text{ (metres per second).}$$

The velocity of the wind may be found with the same instrument if we allow the log to pay out from a fixed point or from a captive air-ship. It is equally easy to derive the absolute (*i.e.* independent) velocity (v) of the air-ship after the values of v' and w in the direction of the wind have been determined.

If we have found these values we can find the angle β from the above equation, and so determine the course which must be made with respect to the compass.

On account of the frequent alterations in the strength and direction of the wind in the region traversed by the air-ship, it is necessary to keep ever on the alert, and to constantly regulate the direction of the keel line.

B.—ASTRONOMICAL NAVIGATION.

If the earth is completely hidden from view by clouds, or if in a night voyage the illumination due to the moon is not powerful enough to enable the course of the air-ship to be determined geographically, it may be found by the altitudes of stars (sun, moon, planets, and fixed stars) with the aid of a chronometer, provided, of course, that at least one star is visible.

The determinations are carried out in a similar manner to those made on board a ship, with this difference—an artificial horizon must be used in the case of an air-ship, since the natural horizon of the aeronaut is usually misty and indistinct.

Bartsch von Sigsfeld (*Z. f. L.*, 1898, p. 5) gives a description of an artificial horizon used by him, which consists essentially of a suspended silvered plane mirror, the vibrations of which are damped by immersing a part of it in a glycerine bath.

Two cases must be taken into consideration in carrying out the measurements.

(*a*) Simultaneous measurements of the altitudes of two or more stars may be possible. The position of the air-ship may now be calculated trigonometrically.

(*b*) Two measurements of the altitude of the same star at a known interval of time are taken, the distance traversed in that interval being computed from the log.

The *Nautical Almanac* gives all the necessary data for the above nautical calculations in tables, which are drawn up with respect to the meridian of Greenwich.

Measurements of altitudes of stars under 10° must be avoided, for the refraction in the lower strata of air gives rise to considerable errors. (*Cf.* Breusing's *Steuermannskunst*, newly rewritten and published by Dr C. Schilling, Leipzig, 1902; *Leitfaden für den Unterricht in der Navigation*, Berlin, 1901; Dr A. Marcuse, *Handbuch der geographischen Ortsbestimmung*, pp. 327 *et seq.*, Braunschweig, 1905.)

C.—AEROSTATICAL NAVIGATION.

The maintenance of the air-ship in aerostatical equilibrium requires special precautions, of which the laws laid down in Chapter VI. form the basis. The especial difficulties in the case of an air-ship are due to the fact that the different divisions of the balloon lose gas at an unequal rate, and to the fact that the ballast is distributed over the whole length of the vessel, and must be used as required to maintain the stability of the axis.

In unstiffened air-ships the small air-balloon must be kept taut all the time. Further aids are the horizontal rudder, the movable weight, and the gas-valves. The aerostatical navigation is governed by the barometer and by a not too sensitive spirit-level, which must be placed exactly in the keel line of the air-ship.

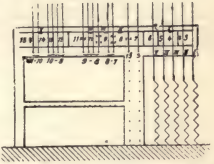


FIG. 138.—Arrangement of ballast and gas ropes in Graf v. Zeppelin's air-ship.

In Graf von Zeppelin's air-ship, which was furnished with four valves and fourteen ballast-holders each to contain 50 kg., the aerostatical navigation was made easier in a convenient manner (as shown by the accompanying figure; fig. 138) during the trials, by having all driving arrangements and valves controlled from one switch-board. The figures on the boards show on the right the valve-lines I. to V.; on the left, the ballast sack-lines numbered according to

the cells to which the sacks belong. Above there is a plan of the air-ship cells in which the ballast sacks are denoted by crosses and the valves by Roman numerals.

§ 7. LANDING WITH AIR-SHIPS.

A safe landing is possible only on water unless special arrangements (air-ship harbours) and personal assistance to hold down the air-ship are available. Since with rigid air-ships even a slight bump on the earth may do damage, it is obviously much safer to land on water. In practice it is never possible, even by working the motor against the wind, to avoid a certain amount of bumping, since the aerostatical equilibrium is not easily judged and allowed for, especially in strong winds. On this account the safer water landing is always preferable.

An air-ship can be anchored more easily with the point against the wind on water. It is quite impossible to anchor on land when assistance is not forthcoming to hold down the air-ship. On water also the air-ship will give a little to side winds and to alterations in the direction of the wind, without overturning. On land, this danger is not excluded even with rigid air-ships. Of course a water-tight and sea-worthy car is a necessary condition for landing on water.

The landing requires great attention, and rapid, decisive handling and management on the part of the aeronaut. As soon as the possibility of air-ship travelling is open to the general public, special charts will be produced, which will give particulars of natural air-ship harbours in different winds, and also of any artificially built harbours. It would be highly dangerous to undertake air-voyaging without such stations against storms and weather, and for renewing supplies of gas, driving material, and ballast.

CHAPTER XIII.

ON FLYING MACHINES.

By Major HERMANN HOERNES,
Salzburg.

§ 1. INTRODUCTORY.

Comparatively little work has been done in investigating the dynamics of flight. The theory of the resistance of the air has received much more attention, though here also are many points yet to be investigated.

In articles published hitherto on the dynamics of flight very few problems have been thoroughly worked out by practical men; on these grounds, therefore, the following compilation must necessarily appear incomplete.

§ 2. NOTATION EMPLOYED.

No definite system of notation has, up to the present time, been adopted for use in aeronautics, and, as in most mathematical and technical works, the same quantities are frequently denoted by different letters by different authors, causing much unnecessary annoyance and trouble. In this and the following chapters we shall use the following notation:—

1. Aero-Technics.

1. F = the area of an aeroplane surface in square metres.
2. α = the angle made by the surface with the direction of flight.
3. β = the angle made by the direction of flight with the horizon.
4. γ = the angle made by the surface with the direction of the propelling force.
5. δ = the angle made by the direction of the propelling force with the horizon.

We have then:

$$\alpha + \beta = \gamma + \delta .$$

6. μ = a particular coefficient for an arched (concave) surface.
7. ζ = a particular coefficient for a raised (convex) surface.
8. R' = the head resistance measured in kilograms on a plane surface moved perpendicularly against the air.
9. R = the head resistance measured in kilograms on a plane surface moved obliquely against the air.

The corresponding horizontal and vertical components are indicated by the suffixes x and y, and are:

10. R_x, R_y, F_x, F_y.

2. Elasticity.

1. δ = thickness.
2. d = diameter.
3. I = geometrical moment of inertia of a cross sectional area.
4. M = bending or torsional moment.

3. Velocities.

1. v = the velocity of an air-ship in still air, or of a surface relatively to the air.
2. u = velocity of the wind relatively to the earth.
3. c = velocity of the air-ship with respect to a fixed point on the surface of the earth.

4. Weights, Pressures, and Forces.

1. a = atmospheric pressure.
2. P = load.
3. Q = weight of apparatus.
4. G = buoyancy, lifting power, or lift of a surface.
5. T = lift of a flying machine $= G - Q$.

5. Mechanics.

1. E = effectual power in metre kilograms per second.
2. A (A_x, A_y) = work.
3. N = effectual power in H.P.
4. η = efficiency.
5. n = number of revolutions per minute.

6. Physics.

1. m = mass.
2. t = time in seconds.
3. s = length of path in metres.
4. g = acceleration of gravity $= 9{\cdot}81$ m. per sec. per sec.

5. γ = weight of 1 cubic metre of air.
6. t_0 = temperature of 0° C.
7. b_0 = pressure of 760 mm. mercury at 0° C.
8. p = pressure of x atmospheres.

§ 3. METHODS OF DETERMINING THE LAWS RELATING TO THE RESISTANCE OF THE AIR.

We shall assume that, within the limits of speed attainable by aeronauts—say up to 50 m. per sec.—the head resistance offered to the air is the same whether a surface is moving forward with a velocity v in the still air, or is imagined anchored fast and met by air moving uniformly with the same velocity.

Experimental determinations of the magnitude of the resistance should be made in still air, *i.e.* in a large enclosed space. In experimenting in the open air, the uncertainty as to the influence of wind and weather detracts from the value of any results. The wind is always irregular, both in direction and strength. So many possible sources of error arise in experiments in open air, that we consider it unnecessary to deal further with these, but shall confine our attention to those made under more suitable conditions.

For further particulars relating to open-air experiments, consult Hoernes on "Die Wellnerschen Versuche über den Luftwiderstand und mit dem Segelrad," *Technische Blätter*, vol. 26; also M. S. P. Langley, *Expériences d'Aérodynamique*; Phillips and Maxim, in the twenty-third *Report of the Aeronautical Society of Great Britain*, and *R. d. l'A.*, 1892; experiments made by Cailletet and Collardeau on the Eiffel Tower, *R. de l'A.*, 1892, and described also by Colonel Touche in 1893; also the experiments of Canovetti and Le Dantec (*cf. I. A. M.*, 1901, p. 107, and 1902, p. 53). Lilienthal's experiments on arched surfaces belong also to this class. See also Hergesell, "Der Flug des Registrierballons," *I. A. M.*, 1897, p. 48.

Conditions for satisfactory measurements of the resistance of the air.—In addition to apparatus which is necessarily extremely sensitive, and large covered rooms, we must, in order to obtain accurate measurements, have thorough experience in handling the apparatus, make frequent repetitions of the same experiments, take special care that no disturbing influences affect the result, and have diligence and patience, time and money at our disposal.

Ritter von Loessl's method.—The apparatus and methods of measurement employed by von Loessl fulfil these numerous conditions. He used (*a*) rotational apparatus, (*b*) balancing apparatus.

For details connected with the former method, see *Sitzungsberichte der Fachgruppe für Flugtechnik des österreichen Ingenieur und Architekten-Vereins*, 1881 and 1882, and his chief work, *Die Luftwiderstandsgesetze, der Fall durch die Luft und der Vogelflug*, Vienna, 1896.

For details in connection with the balance method consult article on "Ein neues experimentelles Verfahren zur Messung von Luftwiderständen," in the *Zeitschrift des österreichen Ingenieur und Architekten-Vereins*, 1894.

§ 4. THE LAWS GOVERNING THE RESISTANCE OF THE AIR.

References:—Newton, Euler, Borda, Hutton, Vince, Désaguilliers, etc. Poncelet, Introduction; Duchemin and Thibault, *Recherches expérimentales*; Weissbach, *Lehrbuch der theoretischen Mechanik*, p. 1181; Hütte, 18th Edition I., p. 261; von Loessl, *Studie über aërodynamische Grundformeln an der Hand von Experimenten*, Vienna, 1881, and *Die Luftwiderstandsgesetze, der Fall durch die Luft und der Vogelflug*, Vienna, 1896; von Loessl, "Der aërodynamische Schwebezustand einer dünnen Platte und deren Sinkverminderung," in the *Zeitschrift des österreichen Ingenieur und Architekten-Vereins*, 1898 and 1899; Langley, *Expériences d'Aérodynamique*, also *Revue de l'Aéronautique*, 1891; Wellner, *Versuche über den Luftwiderstand gewölbter Flächen im Winde und auf Eisenbahnen*, 1893; Hoernes, "Besprechung der Wellnerschen Luftwiderstandsversuche," *Technische Blätter*, vol. 26, Prague, 1895; Wuich, *Lehrbuch der äusseren Ballistik*; Hoernes, "Das Loesslsche Luftwiderstandsgesetz und seine Anwendung in der Flugtechnik," special number of the *Technische Blätter*, 1900.

1. **General considerations.**—When moving air strikes against any body its kinetic energy diminishes, like that of every other moving body which strikes a stationary one. The force exerted by the moving air is proportional to the product of its mass into the square of its velocity.

2. **Newton's laws of the resistance of air.**—If the velocity of a body at a time t and during an infinitely small period dt is equal to v, and if it displaces a mass of air m during this time, it overcomes the resistance of the air by imparting to it its own velocity v. The corresponding force is $\frac{mv}{dt}$, or, if we denote the path traversed in the time dt by ds, then $v = \frac{ds}{dt}$ and

the force $=\frac{mds}{(dt)^2}$. The mass m is, however, proportional to the length of path traversed, and we may write $m=\mu ds$. Substituting this value in the above equation, we get the force necessary to overcome the above resistance $=\mu\left(\frac{ds}{dt}\right)^2$ or μv^2.

The effect of the resistance of the air is the same as if the body were acted upon by an opposing force varying as the square of the velocity. It follows, therefore, that the diminution in velocity in any second is proportional to the square root of the actual velocity. μ is a coefficient depending on the shape of the body.

3 **Ritter von Loessl's law of the resistance of the air.**—von Loessl has propounded the following laws relating to the resistance of the air, based on numerous actual experiments.

For velocities ranging between 0 and 50 m. per sec., the head resistance opposing a surface moved perpendicularly against an unlimited air medium, or met perpendicularly by uniformly moving air, is given by :—

$$R'=\frac{\gamma}{g}\,F.v^2 \qquad (1)$$

The pressure on a surface moved obliquely against the unlimited air medium, or struck obliquely by uniformly moving air, is

$$R=\frac{\gamma}{g}\,Fv^2\sin\alpha \qquad (2)$$

which may be resolved into the two components

$$R_y=\frac{\gamma}{g}\,Fv^2\sin\alpha\cos\alpha \qquad (3)$$

$$R_x=\frac{\gamma}{g}\,Fv^2\sin^2\alpha \qquad (4)$$

These four fundamental formulæ, which hold with the highest degree of accuracy, even for quite small angles, have been deduced from the results of very exact experiments carried out by Freidrich Ritter von Loessl. The experiments showed that small and large surfaces experienced resistances simply proportional to their sizes.

"Since in these experiments surfaces varying in area from 0·0017 up to 2 sq. m. were used, *i.e.* a variation of some thousandfold in size, and driving weights of from 50 gm. to 30,000 gm., *i.e.* a variation of six-hundredfold, in combination with inclinations of from 90° to 1°, the smallest analytical or other error in the derivation of the formulæ must have led to marked differences, quite changing the character of the results.

Hence the equations derived above must represent the correct relations between F, v, α, γ, and g."

4. von Loessl arrived at the same result by analytical methods. His method of deducing it was as follows :—

If a surface moves forward with a uniform velocity v, it displaces per second a mass of air $Fv = q$, and since this air must be forced out sideways, an equal quantity of air is displaced at the sides. The total weight of air set in motion is therefore

$$G = q + q = 2\gamma Fv.$$

The energy necessary is

$$L = \frac{mv^2}{2} = \frac{Gv^2}{2g} = \frac{\gamma}{g} Fv^3.$$

Since, however, $L = R'v$, it follows that

$$R' = \frac{\gamma}{g} Fv^2.$$

5. R represents the normal pressure acting on the surface, and acts, *a priori*, perpendicularly to the surface if it be plane. In the case of an arched surface Lilienthal found that the components are bent more forward the smaller the angle α (see *Der Vogelflug*, p. 63, *cf.* also Chap. IX. § 2). von Loessl has not expressed a definite opinion on this point. Popper, in his "Flugtechnische Studien," in the *Zeitschrift für Luftschiffahrt*, 1896, p. 201, and Jarolimek ("Über das Problem dynamischer Flugmaschinen," in the *Zeitschrift des österreichen Ingenieur und Architekten Vereins*, 1893), doubt the correctness of Lilienthal's analysis, while Wellner and others deem it correct.

In connection with the proportionality of the resistance to the area, Broda, Hutton, and Thibault found from their researches that the resistance increased with the absolute size of the surface (Poncelet, *Méc. ind.*, 616 and 617), whereas Dines, who made his experiments with sensitive anemometers, holds the contrary to be true (v. Fergusson, in the *Proceedings of the International Conference on Aerial Navigation*, held in Chicago, 1894). Experiments, instituted by Baker on the Forth Bridge, on the pressure of the wind, tended to confirm Dines' hypothesis. It is open to doubt, however, as to whether these measurements were made to the same degree of accuracy as those carried out by von Loessl, which also, as regards the surface proportionality, have been confirmed by experiments carried out by Canovetti and by the Abbé Le Dantec (*cf. I. A. M.*, 1901).

6. The value of γ, the density of the air, depends on the height of the atmospheric layer to which it refers, and varies also with the temperature.

1 cb. m. air at 0° C. at sea level (where $a = 10{,}364$ kg. weight per sq. m.) weighs 1·293 kg.
,, 1000 m. height it ,, 1·145 ,,
,, 2000 m. ,, ,, 1·010 ,,
,, 3000 m. ,, ,, 0·892 ,,

The density of the air varies with the temperature and the height of the barometer.

At a temp $t_0 = 0°$ C., and under a pressure $b_0 = 760$ mm., the density $\gamma_0 = 1{\cdot}293$ kg. per cb. m., while at any other temp. $t°$ C. and pressure b mm.

$$\gamma = 1{\cdot}293 \cdot \frac{b}{760} \cdot \frac{273}{273+t} \quad . \quad . \quad . \quad (5)$$

A correction ought also to be applied for the humidity of the air.

7. von Loessl has computed the following table for the values of $\frac{\gamma}{g} = \frac{\gamma}{9{\cdot}81}$:

Barometric pressure in mm.	Temperature in ° C.							
	−5	0	+5	+10	+15	+20	+25	+30°
	Value of $\frac{\gamma}{g} = \frac{1}{\cdot\cdot\cdot\cdot\cdot}$							
770	7·350	7·486	7·627	7·773	7·924	8·080	8·243	8·413
760	7·449	7·585	7·727	7·874	8·027	8·186	8·352	8·525
750	7·549	7·687	7·830	7·979	8·134	8·285	8·464	8·639
740	7·651	7·791	7·936	8·087	8·244	8·408	8·578	8·756
730	7·755	7·897	8·045	8·198	8·357	8·523	8·695	8·875
720	7·862	8·006	8·156	8·311	8·472	8·640	8·815	8·998
710	7·972	8·118	8·271	8·428	8·591	8·761	8·938	9·123
700	8·085	8·234	8·388	8·549	8·714	8·886	9·065	9·253
690	8·202	8 353	8·509	8·672	8·840	9·015	9·196	9·387
680	8·323	8·476	8·634	8·799	8·971	9·148	9·331	9·524

8. The shape of the experimental surface affects the resistance, and the resistance given by the formula $R = \frac{\gamma}{g} F . v^2$ is indeed the maximum possible value, only attainable with a certain form of figure.

This maximum holds when the direction of motion is perpendicular to the surface, and when the edges of the surface are raised, or the forward side of the surface is concave. The area F must therefore be multiplied by a factor ζ, depending on the shape of the surface; ζ has the values given below for the particular cases enumerated.

$\zeta=1$ if the surface is concave, or if it is provided with edges so that the concave side moves forward.

$\zeta=0{\cdot}83$ for a plane circular surface.
$\zeta=0{\cdot}86$,, square surface.
$\zeta=0{\cdot}90$,, equilateral triangle.
$\zeta=0{\cdot}92$,, isoceles right-angled triangle.
$\zeta=0{\cdot}94$,, right-angled triangle whose sides are as 1 : 4.

For obliquely inclined surfaces the form must be taken as that projected on a plane, perpendicular to the direction of motion. Since the latter usually takes more and more the figure of a long rectangle as the inclination increases, the deviation of the pressure coefficient from unity gradually diminishes in a similar proportion, so that often with surface inclined at 45° it can no longer be observed with certainty. With still smaller angles there is no trace of it, and we may take $\zeta=1$.

In front of the surface there will be a cone of still air formed. Its slopes make an angle of 45° with a surface moved perpendicularly against the air. The air contained in the projection is in stable equilibrium under the uniform pressure on every side, and suffers a corresponding compression, and transfers finally the pressure received uniformly to the surface.

This air projection was first discovered by v. Loessl. *Cf.* pp. 31–61 and 99-124 *Luftwiderstandsgesetze.*

v. Loessl's experiments showed, further, that the roughness or smoothness of the surface does not influence the head resistance, and, as a matter of fact, even depressions and elevations in the surface are without influence up to the limit at which they alter the general form of the surface.

9. The friction of the air is directly proportional to the velocity. Very few results have been published relating to the external friction of the air. It can, however, be measured by v. Loessl's balance apparatus.

The coefficient of internal friction of the air is constant down to a pressure of 0·6 mm.

The values for the coefficient of friction of air, as found by various observers, are tabulated below. These are given in milligrams weight acting on a surface of 1 sq. m. situated at a distance of 1 mm. from another surface and moving with a relative velocity to it of 1 mm. per sec., the temperature being 15° C.

The value is, according to	v. Obermayer, . .	0·00000177
	Maxwell, . . .	0·00000202
	O. E. Meyer, . .	0·00000193
	Puluj, ...	0·00000186
	Kundt and Warburg,	0·00000191

The fact that masses of air are moved as though attached to the body, the influence of which is especially marked in irregular movements—*e.g.* pendulum motion—was discovered by du Buat.

In the case of a sphere the volume of the attached air is equal to 0·6 times the volume of the sphere; in the case of a prismatic body moved in the direction of the axis, the ratio of these volumes is $0{\cdot}13+0{\cdot}705\frac{\sqrt{F}}{l}$. See Bessel, Sabine, Baily, etc.

10. Concave obliquely-placed surfaces offer a head resistance greater than that of a plane surface.

Its magnitude varies with the form of the surface, its "arching" and inclination, and is therefore not a constant, but must be determined separately for each form and inclination.

In general the following relations hold:—

$$R'_\mu=\mu\frac{\gamma}{g}.\,Fv^2 \qquad (6)$$

$$R_\mu=\mu\frac{\gamma}{g}.\,Fv^2\sin\alpha \qquad (7)$$

$$R_{\mu x}=\mu\frac{\gamma}{g}.\,Fv^2\sin^2\alpha \qquad (8)$$

$$R_{\mu y}=\mu\frac{\gamma}{g}.\,Fv^2\sin\alpha\cos\alpha \qquad (9)$$

where the coefficient μ is greater than 1.

For convex surfaces similar formulæ hold, with the difference that the coefficient η is less than 1. This coefficient also depends on the form of the convex surface, its inclination, and perhaps also its speed.

In order to use the formulæ 6–9 for convex surfaces, η must be used instead of μ.

A keel turned with its edge against the air behaves as if its side surfaces were moved with the same inclinations singly against the air.

The laws of the resistance of the air found by von Loessl have been taken by most aeronauts as the basis of their calculations, up to velocities of 50 m. per sec.

§ 5. LAWS OF THE RESISTANCE OF AIR FOUND BY OTHER EXPERIMENTERS.

1. In discussing Wellner's experiments on the resistance of the air ("Die Wellner'schen Versuche über den Luftwiderstand

und mit dem Segelrad," in the *Technische Blätter*, vol. xxvi., 1895), Hoernes points out the great variety of formulæ applicable for calculating air resistances.

In the most general form the law for a surface moved normally may be written $R = \zeta F v^2$.

The density of the air enters into the factor ζ, which cannot, therefore, possess a constant value. Notwithstanding this it has been much experimented upon.

Up to the present time the following numerical values have been obtained by different experimenters for the value of ζ reduced to 15° C. and a pressure of 762·3 mm. :—

Observer.	ζ	How obtained.	Where published.
Lord Rayleigh,	0·055	From theoretical considerations.	"On the Resistance of Fluids," *Phil. Mag.*, 1876.
Morin, . . .	0·082	Movement in a circle.	
Piobert, . .	0·082	,,	
Didion . . .	0·082	,,	
Smeaton, . .	0·122	,,	
Hagen, . . .	0·071	From the friction on the edges.	Relates to rectangular plates.
Recknagel, .	0·070	Movement in a circle.	"Über Luftwiderstand," *Zeitschrift d. Vereins deutscher Ingenieure*, 1886.
Marey, . .	0·125 0·13	,,	
Goupil, . . .	0·125	,,	*La locomotive aérienne*, 1884.
v. Loessl, . .	0·125	Movement in a circle and balancing apparatus.	*Die Luftwiderstands-gesetze.*
Renard, . .	0·085	Movement in a circle.	*Revue de l'Aéronautique*, 1888.
Langley, . .	0·080	,,	*Revue de l'Aéronautique*, 1891.
Cailletet and Colardeau, .	0·071	Movement in a straight line.	*Comptes Rendus*, 1892.
Poncelet, .	0·098(?) 0·067	...	*Méd. ind.*, 601 and 623.

The large differences observed in the values of the magnitude of the air resistance may also be readily seen from the following results.

Thus Weissbach gives the following formula :—

$$R = \zeta \frac{v^2}{2g} F\gamma \text{ where } \zeta = 1{\cdot}86.$$

du Buat and Thibault give the following resistance coefficients :—

$\zeta = 1{\cdot}86$ for a blast of air against a still plane surface, and
$\zeta = 1{\cdot}25$ if the surface moves and the air is still.

In each case the front face receives two-thirds and the rear one one-third of the whole action.

For a surface rotating Didian found

$$\zeta = 1{\cdot}573 + 0{\cdot}681\, v^{-2},$$

and for the same moved normally

$$\zeta = 1{\cdot}318 + 0{\cdot}565\, v^{-2}.$$

Thibault found for the latter case

$$\zeta = 1{\cdot}865 + 0{\cdot}565\, v^{-2}.$$

Piobert and Duchemin give:

$$R = 0{\cdot}029(1 + 0{\cdot}0023v)Fv^2, \text{ whence}$$
$$\zeta = 0{\cdot}451(1 + 0{\cdot}0023v).$$

According to Eytelwein $\zeta = 0{\cdot}7886$.
According to Robins and Hutton for

$v=$	1	5	25	100	200	300	400	500	600 $\frac{\text{m.}}{\text{sec.}}$
$\zeta=$	0·59	0·63	0·67	0·71	0·77	0·88	0·99	1·04	1·01.

Professor Hergesell (*I. A. M.*, 1897, p. 48) gives the following formula for the resistance of a spherical balloon :—

$$\frac{R}{g} = \frac{0{\cdot}041}{g} \cdot \frac{m}{M} \cdot v^2.$$

In this formula m = the absolute weight of the displaced air, M the weight of the balloon, v the upward velocity.

The total resistance of the balloon is

$$\frac{RM}{g}(kg) = \frac{0{\cdot}041}{g} mv^2 \quad . \quad . \quad . \quad . \qquad (10)$$

or

$$= \frac{m}{n}\left(n - 1 - \frac{\beta}{s}\right)$$

$$= \frac{m}{2{\cdot}23}\left(1{\cdot}23 - \frac{\beta}{s}\right);$$

n = the ratio of the specific weight of air to that of the gas, $\beta = \frac{B}{\gamma}$ the specific load of the balloon, sg = the specific weight of the gas.

2. The power in which $\sin\alpha$ enters into the expression has also been much debated; v. Loessl uses it, like Vince in the case of water, Thibault (1856), Renard (beginning of 1870), and Goupil (1884), in the first power, and confirmed this by a very pretty experiment, using a frame which could revolve about a central axis in the air, to which a plane surface was fixed, another similar surface being fixed at any angle α to the plane of the frame. During the motion the frames placed themselves so that the two surfaces stood vertically, which can only occur theoretically on the assumption that the first power of the sine enters into the expression (v. Loessl, p. 135).

We have therefore

$$R_x = R \sin\alpha.$$

Rayleigh finds: $$\frac{R\alpha}{R_{90}} = \eta = \frac{(4+\pi)\sin\alpha}{4+\pi\sin\alpha}.$$

("On the Resistance of Fluids," *Phil. Mag.*, 1876, and Gerlach, "Einige Bemerkungen über den Widerstand, etc.," *Civilingenieur*, vol. xxxi.).

Louvrié puts $$\eta = \frac{2(1+\cos\alpha)\sin\alpha}{1+\cos\alpha+\sin\alpha}.$$

(*Revue de l'Aéronautique*, 1890.)

Duchemin: $$\eta = \frac{2\sin\alpha}{1+\sin^2\alpha}$$

(with which Langley's measurements agree).

Renard: $$\eta = a\sin\alpha - (a-1)\sin^3\alpha$$

(where $a=2$; see *Séances de la Société française de Physique*, 1889, p. 19).

Weissbach: $$\eta = \sin^4\alpha.$$

The following table gives the values of α taken from the figures of Hutton and Thibault in Poncelet's *Mécanique Industrielle* and from v. Loessl's work:

The head resistance N is, according to

	Hutton.	Thibault.	Duchemin.	Weissbach.	Louvrié.	Rayleigh.	Langley.	v. Loessl.
$\alpha = 0°$	..	..	0·035R	0·000R	0·035R	..	..	0·017R
$\alpha = 5°$	0·27(?)	..	0·174	0·008	0·167	0·146	0·150	0·087
$\alpha = 10°$	0·264	0·328	0·337	0·030	0·319	0·273	0·300	0·174
$\alpha = 15°$	0·351	0·420	0·486	0·067	0·457	0·384	0·460	0·259
$\alpha = 30°$	0·750	0·764	0·800	0·250	0·789	0·641	0·780	0·500
$\alpha = 45°$	..	..	0·945	0·500	1·000	..	..	..

§ 6. DEDUCTIONS FROM THE LAWS OF THE RESISTANCE OF THE AIR.

See v. Loessl, *Luftwiderstandsgesetze*, pp. 149 *et seq.*

$$R_x = R_y \tan \alpha$$

$$A = \sqrt{\frac{g}{\gamma} \frac{R_y^3}{F} \frac{\sin \alpha}{\cos^3 \alpha}} = R_y v \tan \alpha$$

$$R_y = \cos \alpha \sqrt[3]{\frac{\gamma}{g} \frac{A^2 F}{\sin \alpha}} = R_x \cot \alpha = \frac{A \cot \alpha}{v}$$

$$F = \frac{g}{\gamma} \frac{R_x}{v^2 \sin^2 \alpha} = \frac{g}{\gamma} \frac{A}{v^3 \sin^2 \alpha} = \frac{g}{\gamma} \frac{R_y}{v^2 \sin \alpha \cos \alpha}$$

$$= \frac{g}{\gamma} \frac{R_y^3 v^2 \tan \alpha}{R_x^2 \cos^2 \alpha} = \frac{g}{\gamma} \frac{R_y^3 \tan \alpha}{A^2 \cos^2 \alpha}$$

$$v = \sqrt{\frac{g}{\gamma} \frac{R_x}{F \sin^2 \alpha}} = \sqrt[3]{\frac{g}{\gamma} \frac{A}{F \sin^2 \alpha}}$$

$$= \sqrt{\frac{g}{\gamma} \frac{R_y}{F \sin \alpha \cos \alpha}} = \frac{A \cot \alpha}{R_y}$$

$$\tan \alpha = \frac{R_x}{R_y} = \frac{A}{R_y v}$$

$$\sin \alpha = \sqrt{\frac{g}{\gamma} \frac{R_x}{F v^2}} = \sqrt{\frac{g}{\gamma} \frac{A}{F v^3}}$$

$$\sin 2\alpha = \frac{g}{\gamma} \frac{2R_y}{F v^2}$$

$$\sin \alpha \cos \alpha = \frac{g}{\gamma} \frac{R_y}{F v^2}$$

$$\frac{\cos^2 \alpha}{\tan \alpha} = \frac{g}{\gamma} \frac{R_y^3}{F A^2}$$

§ 7. BODY FALLING THROUGH THE AIR.

The rate of fall may be determined by means of the following formulæ.

The time $t = \frac{k}{2g} \, l \, \frac{k+v}{k-v}$.

The velocity $v = k \, \frac{e^{2\phi} - 1}{e^{2\phi} + 1}$.

The distance fallen through $h = \frac{k^2}{g} \, l \, \frac{1}{2}(e\phi + e - \phi)$,

where $$\phi = g\frac{t}{k},$$

and the constant k is the limiting value which v can attain, being given by

$$v_{max} = k = \sqrt{\frac{g}{\gamma} \cdot \frac{G}{F}}.$$

This limiting value is theoretically only attained after an infinitely long time, but in practice is rapidly reached.

See Duchamel, *Lehrbuch der analytischen Mechanik*, Leipzig, 1858, p. 314; v. Loessl, *Luftwiderstandsgesetze*, pp. 171–229; Hoernes, "Das Loessl'sche Luftwiderstandsgesetz, etc.," special number of the *Technische Blätter*, 1900, pp. 16 and 17.

§ 8. ON THE RETARDATION OF THE FALL.

Z. f. L., vol. v. p. 65; Gerlach, *Ableitung gewisser Bewegungsformen geworfener Scheiben*, etc.; v. Loessl, *Zeitschr. d. öst. Ing. und Arch. Vereins*, Nos. 22–32, 1898, and No. 33, 1899; *Der Aërodynamische Schwebezustand einer dünnen Platte und deren Sinkgeschwindigkeit*; *I. A. M.*, 1903, June. v. Loessl, *Wiederholte Erläuterung des Schwebefluges.*

It is a well-known experimental fact that a flat disc falls more slowly when it has a simultaneous horizontal velocity than when it falls perpendicularly.

v. Loessl gives the following empirical formula:—

$$V = \sqrt{\frac{g}{\gamma} \cdot \frac{G}{(F + bv)}},$$

where V is the velocity of fall of a horizontally placed lamina possessing a horizontal velocity v, G being the weight of the lamina, b its breadth, and $b\,v$ the area swept out in unit time.

The inclination of the path or angle of descent of the lamina is given by:

$$\frac{V}{v} = \tan\,\theta = \sqrt{\frac{g}{\gamma}\cdot\frac{G}{(F+bv)v^2}}.$$

These are both ideal values, the head resistance having been left out of consideration.

The greater b and v the less steep will be the path of flight.

The following formulæ are derived from the above: —

$$A = \frac{\gamma}{g}\,Fv^3,$$

i.e. the work per second done by the resistance, or the propelling power necessary to maintain the horizontal velocity v.

The following formulæ apply to horizontally placed heavy discs:—

$$V_1 = V + \frac{A}{G},$$

i.e. the velocity of descent taking into account the resistance of the air.

$$l = \frac{x}{\tan\,\theta},$$

i.e. the horizontal path which a gliding body can cover from a height x.

The following formulæ apply to horizontally placed discs driven by propelling force:—

$$A_1 = VG,$$

i.e. the total work per second which is necessary to force a surface falling with a velocity V into a horizontal path.

$N = \dfrac{VG}{75}$ is the H.P. necessary for this purpose.

$$A + A_1$$

is the total work per second which must be performed to ensure gliding in a horizontal plane, including the work necessary to overcome the head resistance. This work is a minimum for a certain velocity.

$$\tan\,\epsilon = \frac{A + A_1}{vG} = \frac{V}{v},$$

i.e. the tangent of the angle of elevation of the surface corresponding to the total work $A + A_1$.

For calculating the upward gliding in a path rising 1 in y, we may employ the following formulæ:—

$$L = A + A_1 + A_2,$$

where $A_2 = \frac{vG}{y}$, the work necessary per second to lift the surface out of a horizontal into the ascending path.

$$\tan \epsilon = \frac{L}{vG},$$

i.e. the tangent of the corresponding angle of elevation in the ascending path.

§ 9. FUNDAMENTAL LAWS OF AERODYNAMICS.

Several very valuable deductions can be made from the above fundamental equations by setting several quantities equal to one another and varying the other factors.

It follows, for example, that $R_y = C\sqrt[3]{A^2}$, and hence the law that the increase of the propelling force for flying machines with constant F_1 and α does not produce a proportionate increase in lifting power, but only an increase in the ratio $\frac{1}{\sqrt[3]{A^2}}$.

From $A = \frac{1}{C}\sqrt{R_y^3}$ it follows that $R_y^3 = C^2A^2$, and hence the law:

"A flying machine can exert a greater lifting power in proportion to the propelling force the smaller this propelling force"; and further, "of two aeroplanes moving forwards, the one moving more rapidly requires a greater propelling force to cover a given distance, but since the lifting power and velocity increase simultaneously a shorter time is required."

From $A = R_y v \tan \alpha$ it follows that, if v and α are constant:

The total work necessary to cover a certain distance is proportional to the load of the apparatus, *i.e.* with two flying machines, one n times as heavy as the other, n times as much work must be performed, under otherwise similar conditions, to cover any fixed path: the heavier apparatus requires, however, n^2 times the power, but flies twice as rapidly and requires the greater propelling power only half as long as the lighter apparatus.

The relations between F and A,
F and R_x,
F and R_y,

and between $\frac{\gamma}{g}$ and all the remaining functions, are those of simple proportionality.

The lift $R_y \left(\frac{\gamma}{g}, \text{ F, and } \alpha \text{ being constant}\right)$ varies as the square root of the velocity, and conversely the velocity varies as the square of the lift. Corresponding relations hold also for the head resistance R_x.

If one flying apparatus is required to attain n times the velocity of another one, it must be able to exert n^2 times the power.

The resistance of an aeroplane varies with the square of the sine of the angle of inclination, *i.e.* the smaller α, the less the resistance.

The lifting power increases as the product of sine and cosine. This is a maximum when $\alpha = 45$,—the head resistance must, however, also be taken into account, so that the maximum is actually attained for a smaller angle than 45°.

From the formula $v = \sqrt{\frac{g}{\gamma} \cdot \frac{G}{F}}$ it follows that, if a body is made smaller or larger without altering its weight and form, the relations existing previously between the head resistance, the weight, and the velocity of fall no longer hold. The value G increases as the cube of the linear dimensions, and the value F as the fourth power; hence the relations holding previously are completely disturbed. It is impossible, therefore, on account of the resistance of the air, to increase the size of a flying body proportionally according to any fixed scale, without thereby decreasing its relative power, hence we cannot expect that a flying model will still glide in the air when it is increased in size ten or a hundredfold This fact should be borne in mind when questions arise relating to flying machines which are to be made on a large scale from small models.

Just as the maximum velocity may alter, all the remaining relationships between the body and the air medium no longer remain the same, and it is evident that smaller bodies in general encounter a proportionately greater air resistance and sink more slowly through the air than larger ones, and that it never follows that bodies will possess the same properties with respect to the air when increased or diminished in size.

§ 10. TYPES OF DYNAMICAL AIR-SHIPS.

Dynamical air-ships include all those forms of air-ships which are not supported in any way by balloons, and which can travel in any given or desired direction with at least one person as load. They are *à priori* heavier than the atmospheric air.

The motion can take place either in straight lines or in

curved paths. If the movement takes place in a wave-shaped path, the air-ship is termed a wave flyer, otherwise a direct flyer.

With the help of flying machines passengers will be transported through the air solely by the power exerted by the motors carried. In order that this may be possible, the whole weight of the complete flying machine, including that of the passengers, must be raised by a force acting vertically upwards. In every type of flying machine this upward force is obtained by driving inclined surfaces through the air by a motor. The resistance offered by the air to this motion has an upward component which furnishes the requisite lifting power.

The surfaces are attached to a suitable framework, which carries both the passengers and the motors, as well as steering and landing arrangements.

The laws of the resistance of the air, now known fairly thoroughly, thanks to the numerous and painstaking experiments of von Loessl and others, give us all the factors which enter into the preliminary calculations of air-ship design.

It is our object to choose among the several factors those which on the one hand satisfy the various equations, and on the other hand are actually attainable in practice. We know from actual natural phenomena that our ultimate object is not beyond attainment, and that we are not pursuing an impossible ideal. We know, for example, that a hurricane—that is, air moving with an enormous velocity, upwards of thirty metres per second—often lifts and carries heavy roofs several hundred metres, overturns railway trains and walls, and even destroys iron bridges weighing very many tons. With fear and trembling we observe the destruction wrought by such rapidly moving air. These natural phenomena point out, with the utmost distinctness, the direction in which a solution of the problem of flight is to be found. Small surfaces must be forced through the air with high velocities by means of light economical motors. The aviator must in the first place use such motors to obtain sufficient power and then direct it into the right paths. In this way it will be possible to employ the energy stored up in the fuel (petrol, benzine, alcohol) carried to serve the purpose aimed at.

1. **Wave flyers.**—These have necessarily broad aeroplane surfaces. In the descending branch of the path the kinetic energy is stored up, which is used again in the ascending branch; and the remaining work necessary is performed by suitable motors.

It is necessary to start at some distance above the ground, and towers with convenient platforms may be used. The

correct timing of the positions of the sail surface is very difficult. There is no continuity of the movement. The landing is difficult.

It is more than questionable if the expected saving of energy is real—the author holds that, even in cases where wave flyers appear advantageous from a theoretical standpoint, the mechanical difficulties more than counterbalance this. Wave flyers have now only historic interest.

Projects:—Zachariae, 1807; Petin, 1850; William Clark, 1865; Lippert, 1876 (Parachüte-Montgolfière); Wellner, 1883 (3 types); Platte, 1883 and 1898; Miller von Hauenfels, 1890; and many others.

Cf. Zachariae, 1807, *Luftschwimmkunst*; Petin, 1850; Lippert, 1876, *Zeitschrift d. österr. Ingenieur-und-Architekten Vereins*; Wellner, 1883, "Der lenkbare Segelballon," *Z. f. L.*, ii p. 161; Pisko, 1885, in *Unsere Zeit*; Platte, "Ein Ballon mit Segelfläche," *Z. f. L.*, iv. p. 356; Jarolimek, "Zu dem Referate A. Plattes über seinen Ballon mit Äquatorialschirm," *Z. f. L.*, ii. p. 338; Gerlach, "Beitrag zur Erklärung des Segelfluges der Vögel, *Z. f. L.*, v. p. 281; Kadarz, "Segelballon," *Z. f. L.*, x. pp. 61 and 291. Miller von Hauenfels, "Die Gesetze des Segelfluges," *Z. f. L.*, xii. pp. 131 and 183, and "der mühelose Segelflug der Vögel"; Popper, 1890, *Flugtechnik*, p. 194; Gostowsky, 1899, "Die Irrlehre vom Wellenfluge," *Z. f. L.*, xviii. pp 211 *et seq.*

2. **Direct flyers**, as distinguished from wave flyers, include all other types of the dynamic flying machine. The principal types known at present may be divided into pure aeroplane machines, screw machines, winged machines.

The physical principle, on which all are based, is as follows:—To set so much air in motion, by a combination of moving surfaces, that the aerostatical buoyancy is greater than or as great as the weight of the flying apparatus. Their form can only be developed from a mechanical standpoint, taking exact account of the laws of the resistance of the air.

The present state of mechanical technology and machine technics enables certain points in connection with the problem to be worked out.

3. **Pure aeroplane machines (kite flyers).** — Aeroplane machines move forwards with the help of surfaces inclined to the horizontal, which are either plane or arched in profile. The effective load is placed underneath the surfaces. These carrying surfaces, usually greater in breadth than length, have a vertical plane surface attached to give stability, a rudder for steering, and a horizontal plane surface, similar to the tail of a bird, for rising and falling. The forward movement is accomplished with the help of screws with horizontal or

slightly inclined axes. Either a single broad surface is used (Henson), or several surfaces superimposed (Stringfellow), or behind one another (*e.g.* Kress), or a step-like arrangement (*e.g.* Maxim). All are variations of the same fundamental idea; the reaction on one or more surfaces moved through the air by mechanical means (with screws or propeller wheels) for lifting purposes.

From observations on ordinary kites we see at once that it is impossible for a kite to rise vertically. The necessary impulse for flight is derived wholly from the forward motion over the ground.

It is not possible for aeroplanes to remain stationary in the air. To maintain the necessary lifting power a rapid forward movement is absolutely essential. It is, therefore, hardly conceivable that the ascent could be made without the help of rails, sliding paths, or a water path. The descent is difficult, and in a wind usually dangerous.

The control of aeroplanes during the actual flight is a matter of great difficulty. The machine can never remain stationary in the air, and on landing it is difficult to avoid shocks which affect the whole machine. Even on water the aeroplane machine is much more liable to damage by the wind than a balloon, as Kress found to his cost in the case of his elegant machine.

How to get over these disadvantages in a satisfactory manner is a problem whose solution seems at present impossible, nor is it likely to be solved in the immediate future, as all the serious defects lie in the very system itself. The pure aeroplane machine in its present form seems, therefore, to offer little advantage to the aviator, although it is, of course, quite possible that after drastic modifications these difficulties may be overcome.

Projects:—W. S. Henson, 1842; Aubaud, 1851; Michael Loup, 1852; Vicomte de Carlingford, 1856; Du Temple, 1857; Le Bris, 1862; F. H. Wenham, 1866; Butler and Edwards, 1867; Kaufmann, 1867; Stringfellow, 1868; Thomas Moy, 1871; Tatin, 1873; Kress, 1880; Philipps, 1884; Pattosien, 1885; Hargrave, 1889; Maxim, 1890; Koch, 1892; v. Sigsfeld, 1893; Graf Carelli, 1898 (2 adjacent arched carrying surfaces; $F = 34$ sq. m., 2 screws on the stern $Q = 159$ kg. (?)). Patents:—Pernington, Rosch, Davidson (1896); Samuelson (1899); Gaerbert, 1897; Rosberg and Nyberg (1900).

Models:—Pénaud, 1871; Joubert, 1872; Tatin, 1889; Steiger, 1891; Philipps, 1882; Hargrave, 1887; Maxim, 1888; v. Sigsfeld, 1893; Kress, 1892; Maxim, 1894; Tatin and Richet, 1890, ($F = 8$ sq. m., 6·6 m. broad, rigid tail; $Q = 33$ kg., $v = 18$ m. per sec., started from an inclined plane, 1896; $N = 1{\cdot}25$ H.P., flew 70 m., 1897, flew 140 m., the apparatus rose in the air and fell

each time into the sea). Mouillard, 1897; ($Q=105$ kg., flew 30 m. at a height of 20 m. in a wind of 20 m. per sec.). Langley's aërodrome, 1896–7, four slightly-arched surfaces on a metal boat, and rigidly attached to the boat. Length of wing, 3·9 m., breadth, 1 m., two driving screws of 1·2 m. diameter, and $n=800$ to 1200; $Q=1{\cdot}36$ kg., $v=14$ m. per sec., covered 1600 m. in 105 seconds. Graf Carelli, Parachute dirigeable, 1898; surface of rotation for the maintenance of stability. Length of small model, 1·6 m.; breadth, 0·6 m.; $F=1{\cdot}125$ m.; propulsion, 1 kg.; arched surface, screw in front of 0·21 m. diameter, covered 200 m. in 40 secs.; $Q=0{\cdot}8$ kg.; the apparatus was released at a height of 6 m., rose 20 m. high, and fell in a flat curve after flying 200 m. in 40 secs. Lt. Vialardi continued Carelli's experiments with a twin screw model 2×3 sq. m. surface, $s=350$ m. at a height of 20 m. The motor weighed 5 kg. Kusmin, 1900; $Q=65$ kg.; $N=3{\cdot}5$ H.P.; $v=30$ m. per sec. (?). Hofmann (1900); $Q=3{\cdot}5$ kg., copper water-tube boiler with 72 tubes, steam engine working at 11·5 atm. pressure; flew 10 m.: momentum for flight acquired on rollers. Whitehead, $F=50$ sq. m.; $N=20$ or 30 H.P.; two wing surfaces as lifting surfaces, $n=700$. Kress, 1900, 1902, etc.; Hargrave, 1901, in Sydney.

B. Penaud's model, weighing ¼ kg., flew 60 m. in 13 secs.; Tatins, Krebs, and Gerstner's models, weighing ¾ kg., flew 40 to 60 m.; Hargrave's, weighing 1 kg., flew 70 m.; Samuelson's, 1·67 kg., 50 m.; and Hofmann's, 3·5 kg., 20 m.

Maxim's flying machine, weighing 4536 kg., having 372 sq. m. aeroplane, and driven by engines of 363 H.P., suffered damage before leaving the ground, rose prematurely, and, owing to the damage having affected the stability, fell and broke.

Neither of Kress's machines could ascend in the air: they were merely tested on water.

Langley's various flying machines, of weights up to 21 kg., made flights up to 1½ km., starting from a raised platform.

References:—W. S. Henson, 1842, in *Aëronautics*, p. 2; Kress, *Aëroveloce*, 1890; Steiger, *Der Vogelflug und Flugmaschine*, 1891; Hargrave, "On Kites," *Engineering*, 1890; Maxim, "Flying Machines," in *Aëronautics*, 1893; Philipps, "On Flying Machines," in the supplement of the *Scientific American*, 1893; Koch, *Die Lösung des Flugproblems*; Lippert, *Flugtechnische Ausblicke*, 1891, "Natürliche Fliegesysteme"; Gerlach, "Der Drachen," *Z. f. L.*, vol. ii. p. 257, v. p. 245; Kadarz, "Zum Drachenflug," *Z. f. L.*, ix. p. 225; Chanute, "Progress in Flying Machines," *I. A. M.*, 1897, p. 4; Kress, *I. A. M.*, 1897, p. 63; Langley, 1901; Kress, 1902; Langley, 1904.

4. **Screw machines** are flying machines deriving their lifting power and forward movement exclusively from air-screws.

We can distinguish between:

1. Screw-machines in which the axis of the screw is stationary.
2. Those in which the axis itself, during the rotation of the screw, turns about a perpendicular axis.

If such screw-machines are required simply to ascend without at the same time making a forward movement, only screws with vertical axes need be used. This is, however, rarely required, but may be useful occasionally as an attachment to a captive balloon.

In all other cases the axes are more or less inclined in order to give propelling as well as lifting power. Special lifting and special propelling screws have also been proposed.

Screw-machines appear much superior to the pure aeroplane machines from the aviatic standpoint. They can raise themselves in the air and remain relatively stationary to the air. They necessitate, in general, no translational but only a simple rotational movement. The surfaces, too, may be much smaller, and therefore lighter. The landing is much safer, since it can be made as gently as we please, even in a strong breeze.

Even the screw machines hitherto devised have had their various drawbacks, which in part at least seem unavoidable. For example, all aeroplanes placed near to the axis are practically useless, even if the angular velocity of the centre of pressure is very great; furthermore, it does not seem to be of any advantage to increase the diameter of the screws beyond a certain size.

In the course of our calculations we obtain abnormally large screw surfaces which at the present are difficult to construct. This is the cause of the non-success of screw machines designed to carry considerable loads.

Jarolimek puts forward the following fundamental rules in an article, "Über das Problem dynamischer Flugmaschinen" (*Zeitschrift des österreichen Ingenieur und-Architekten Vereins*).

Driving screw-blades must be used at a very high rate of revolution, when the angle is extremely small. Instead of few and large blades, many small ones should be employed as long as the weight of the screw-blades per unit area of surface does not exceed the maximum permissible amount.

The weight of the motor, including parts, must be equal to double the weight of the flying apparatus. Screws should be manufactured of sheet steel.

Experiments have shown that small screws with a peripheral velocity of 60 to 80 m. per sec. run at an inclination of one-fifth of a degree. The weight of the aeroplanes should not exceed 3 kg. per sq. m.

The blades should be built long and slender.

Schemes:—Degen, 1817; Cossus, 1845; Le Bris, 1851; Aubaud, 1851; Bright, 1859; De la Landelle, 1863; Castel, 1878; Jarolimek, 1878, and others. Further patentees:—von Schörke, Kosch, Davidson, Dr Beenen, *I. A. M.*, 1898, pp. 91, 95, 114; Breiner, *I. A. M.*, 1900, p. 140; Hoernes, 1905.

Models:—Launay et Bienvenu, 1874; Cayley, 1796; Philipps, 1842; De Ponton d'Amécourt, 1863; Pénaud, 1871; Pettigrew, 1876; Forlanini, 1877 (weight 1 kg., furnished with two screws, rose 13 m. in the air and flew for 15 secs. at a time, *I. A. M.*, 1905, pp. 226 and 331), *l'Aërophile*, 1902, p. 2; Tatin, 1879; Dufaux, 1905; Légèr, 1905; Hoernes, 1905.

References: Jarolimek, "Über die Grundlagen der Mechanik des Fluges," *Z. f. L.*, ii. p. 289; Renard, "La locomotion aérienne," *R. d. l'A.*, 1888, p. 117; Walker and Alexander, "The Lifting Power of Air Propellers," in *Engineering*, 16th Feb. 1900, and in *I. A. M.*, 1900, p. 78; and Buttenstedt, *I. A. M.*, 1900, p. 120; also Kress, *Z. f. L.*, 1900, p. 125, "Die Kaptivschraube" (*cf.* Chap. XIV.).

5. **Winged flying machines.** — These are flying machines which are lifted and driven forwards with the help of bird- or bat-like wings.

They are not furnished with a gas balloon. The majority acquire the requisite air resistance by running or springing from a height. The necessary work is performed by the movement of the wings with the hands or feet, or is furnished by separate small but very powerful motors. The wings are usually arched, but differ from the wings of flying animals in that they are rigid and not penetrated by nerves. The hinged and jointed wings act as single- or double-armed levers, and are always made longer than broad.

Owing to their complicated mechanism and rigid wings, winged flying machines are exceedingly difficult to build at the present day. B. Pichancourt, Kress, and others have succeeded in building small models on this system, the flight being sustained by the flapping of wings. Hargrave's models have hitherto given the best results, two of 1·85 and 1·6 kg. weight respectively having made flights of over 150 m.

The winged machines have one advantage—the flapping stroke. During this stroke the air is alternately compressed and expanded, and the resistance is very much greater than a steady resistance, nine to fifteen times as great, in fact.

Danilewski in 1900 balanced his weight by a balloon and was able to raise the remaining few kilograms by flaps of the wings and so move in any desired direction in the air.

Schemes:—(*Cf.* Chap. XI., *A.*) Besnier, 1678; Marquis de Brequeville, 1743; Abbé R. Desforges, 1772; Murray, 1798;

Degen, 1806–1817; Hengler, 1830; Letur, 1852; de Groof, 1865; Dandrieux, 1874; v. Wechmar, 1886; Koch, 1890; Kress, 1893; and A. Stentzel in Hamburg. (Length from tip to tip, 6·32 m.; breadth, 1·68 m.; angle of stroke of wings, 90°. Total lifting surface, including, rudder 8·125 sq. m.; weight of wings, 10 kg.)

References:—(1) Wechmars, *Flugtechnik*, 2nd vol.; (2) Lilienthal, *Vogelflug*, etc., 1890; (3) v. Parseval, *Die Mechanik des Vogelfluges*, 1889; (4) Marey, *Le vol des oiseaux*, 1890; (5) Jarolimek, "Möglichkeit des dynamischen Fluges mit Beziehung auf die Versuche Lilienthals," *Z. f. L.*, xi. p. 145; (6) Koch, "Der freie menchliche Flug, etc.," *Z. f. L.*, x. p. 9; (7) Kress, "Der persönliche Kunstflug," *Z. f. L.*, xii. p. 105, *I. A. M.*, 1897, p. 22. Also, Moore's Experiments (Patent Specifications, No. 6 of 1895, and *I. A. M.*, 1898, p. 47), ($n=144$, $Q=113$ kg., four wings of 9 sq. m. which carried 12·5 kg. per sq. m.).

Will imitated the Kalong bat; v. Israel's patent, No. 93184, 11th June 1896.

§ 11. AERODYNAMICAL CALCULATIONS.

Preliminary.—This subject is at present in its infancy, very few experimental data being available. What follows is, therefore, only given in default of anything better, and does not profess to be complete.

In all problems connected with the technics of flight, certain quantities enter into the calculations which are intimately related to one another, especially—

$$\frac{\gamma}{g},\ R(R_x,\ R_y),\ F,\ \alpha,\ v,\ G,\ A(A_x,\ A_y),\ E(E_x,\ E_y),\ N(N_x,\ N_y).$$

We have

$$\frac{\gamma}{g}=f(t,\ b) \qquad A=f(R,\ v).$$

$$R=f\left(\frac{\gamma}{g},\ F,\ \sin\alpha,\ v\right) \qquad A_x=f(R_x,\ v).$$

$$G=f\left(\frac{\gamma}{g},\ F,\ \sin\alpha\cos\alpha,\ v\right) \qquad A_y=f(R_y,\ v).$$

In general the treatment depends on the determination of the motion of certain combinations of surfaces through the air. This belongs to one of the most difficult chapters of analytical mechanics, and assumes an exact knowledge of the laws of the resistance of the air.

At the present time such problems cannot be handled with-

out making various assumptions, many of the necessary coefficients not having as yet been determined.

When a surface is moved through the air, work is performed by three elements, each of which must be taken into account:—

1. The weight of the apparatus.
2. The propelling force.
3. The resistance of the air.

We usually know, Q, *i.e.* the load, c the required absolute velocity, and $\frac{\gamma}{g} = \frac{1}{8}$ to $\frac{1}{9}$.

The assumptions may vary, *e.g.* a known value of A, or G, or F and v. Frequently repeated calculations are necessary in order that the assumed and attainable values may agree with one another.

We must have—

$$\left.\begin{array}{l}\text{for horizontal flight}\\ \text{in falling}\\ \text{in rising}\end{array}\right\} \quad R_y \quad \left\{\begin{array}{l}= G\\ < G\\ > G.\end{array}\right.$$

Each of these paths corresponds to a certain rate of revolution of the screws and a corresponding amount of work regulating the ascent or descent.

The relations which we must use in considering horizontal flight, deduced from the laws of air resistance, are—

$$A = (P - R_x)v$$

$$R_y = G$$

$$F = \frac{g}{\gamma} \quad \frac{R_y}{v^2 \sin \alpha \cos \alpha} = \frac{2g}{\gamma} \cdot \frac{R_y}{v^2 \sin 2\alpha}$$

$$v = \sqrt{\frac{g\,R_y}{\gamma F \sin \alpha \cos \alpha}} = \sqrt{\frac{2g\ R_y}{\gamma F \sin 2\alpha}}$$

$$\sin 2\alpha = \frac{2g\ R_y}{\gamma F v^2}.$$

We must, however, consider not only the resistance of the aeroplane, but also that of the whole apparatus.

In order to obtain a clear picture of the processes going on, the following table has been calculated from the formulæ:—

$$v = \sqrt{\frac{g}{\gamma} \cdot \frac{G}{F \,.\, \sin \alpha \,.\, \cos \alpha}} \quad \text{where } G = R_y \text{ and}$$

$$N = \quad \frac{\gamma}{g} \cdot \frac{F v^3 \sin^2 \alpha}{75}$$

on the assumption that G = 5000 kg., F = 500 sq. m. and $\frac{\gamma}{g} = \frac{1}{8}$.

For $\sin \alpha = 0{\cdot}025$	and $v = 60$	m. per sec.	$N = 100$	H.P.
,, ,, $= 0{\cdot}05$	,, $= 45$	,,	,, $= 150$	,,
,, ,, $= 0{\cdot}1$	,, $= 30$	,,	,, $= 200$	,,
,, ,, $= 0{\cdot}2$	,, $= 21$	,,	,, $= 274$	,,
,, ,, $= 0{\cdot}3$	,, $= 18$	,,	,, $= 360$	,,
,, ,, $= 0{\cdot}4$	,, $= 15$	,,	,, $= 400$	,,

Hence if we wish to build a flying apparatus having 500 sq. m. lifting surface, and not weighing more than 5000 kg., then we require a motor giving 400 H.P., in order that a velocity of 15 m. per sec. may be attained. The surface used must be inclined at an angle of 23°·35′ ; or :

If we wish to build a flying machine weighing not more than 5000 kg., and assuming that we can lift 10 kg. load with 1 sq. m. of aeroplane surface and travel at a rate of 30 m. per sec., then we require an expenditure of work equal to 200 H.P., and the surfaces must be inclined to the horizon at an angle of 5°·45′.

Those interested in aviatics are strongly recommended to represent these results graphically.

If we substitute gradually ascending values for v in the equations

$$A = \sqrt{\frac{g}{\gamma} \cdot \frac{R^3_y \sin \alpha}{F \cos^3 \alpha}}$$

$$v = \frac{A}{R_y} \cot \alpha,$$

we easily see that the flying apparatus requires a much greater power in order to maintain its own weight ($R_y = G$) in flight, with a smaller horizontal velocity than with larger velocities.

A flying machine is therefore naturally used with a large forward velocity.

F	G	α	A	v
Assumed.			Calculated.	
0·075	0·3	45°	2·546	8·485
,,	,,	10°	0·768	14·509
,,	,,	5°	0·534	20·363

See v. Loessl, *Z. f. L.*, xix. pp. 222, 238, and 265.

§ 12. INFLUENCE OF THE WIND ON FLIGHT.

General.—Wind is air in motion and is caused by differences of pressure within the atmosphere, arising in consequence of differences in temperature. It is measured in metres per second.

Meteorology concerns itself principally with the determination of the average direction of the wind and its mean velocity, the distribution of winds on the earth, and the daily and annual periods and variations.

The aeronaut must study also the influence of the winds on objects of flight, and the primary and secondary variations of the wind occurring within very short periods, and both the vertical and horizontal components of its velocity.

1. **Types of winds.**—In nature regular winds seldom last for more than a few moments, but the higher we go the longer the periods. Gusts of wind are the rule, at least in the lower strata of the atmosphere.

Our calculations must, at the present time, be made on the assumption that the winds are regular, the other case being too complicated for treatment.

The wind increases in velocity with the height, usually altering both in intensity and direction as we ascend.

2. **Apparatus for measuring the velocity and direction of the wind.**—*Cf.* Lilienthal, *Der Vogelflug*, etc., p. 112; Wellner, *Versuche über den Luftwiderstand*, figs. 1, 2, 11 and 12; Langley, *Aëronautics*, No. 4, 1894.

Robinson's Anemometer, with four hollow hemispheres, only gives average values of the velocity.

3. **The velocity of the wind at great altitudes** increases, as a rule, very rapidly with the height.

If we assume the velocity of the wind on the earth's surface to be unity, then the mean values of the average velocity between different heights above the earth are given in the following table:—

Height of layer in km.,	0–1	1–2	2–3	3-4	4–5	5–6
Relative velocity of wind,	1·75	1·95	2·15	2·50	3·10	4·50

This increase is different in cyclonic or anticyclonic regions, and differs also in the case of east or west winds.

4. **The direction of the wind** varies with the height in such a manner that on the average it is turned more to the right as we go aloft, according to the following table:—

Mean deviation to the right in 1000 m. at a height of	Given by $x°$.	Whence the total deviation is
1000 metres.	15°	15°
2000 ,,	12½°	27½°
3000 ,,	11½°	39°
4000 ,,	1°	40°
5000 ,,	3°	43°
6000 ,,	6°	49°
7000 ,,	6°	55°

Cf. Renard, *R. d. l'A.*, 1888, p. 29, and the epoch-making work by Assmann and Berson, *Wissenschaftliche Hochfahrten*, pp. 199–224, from which the above tables have been taken.

Suggestions as to the scientific investigations of these points were given by Hoernes in 1892, in a pamphlet, *Über Ballonbeobachtungen und deren graphische Darstellung mit besonderer Berücksichtigung meteorologischer Verhältnisse*, pp. 28–40. In Hoernes' book on *Lenkbare Ballons*, the most important results of the German balloon expeditions are summarised on pp. 77–84, and the most important laws relating to the wind are collected on pp. 59–77.

5. **The unsteadiness of air-currents** is shown by the clouds, falls of snow, smoke from chimneys, masses of dust, waves in cornfields, balloon voyages, etc.

Experiments and measurements show that the velocity of the wind may vary enormously within a few seconds.

If we plot time in seconds as abscissae and velocities as ordinates, we obtain more or less wavy lines accompanied by secondary waves in the ascending and descending branches. The theory has not yet been investigated.

Numerous data relating to the varying velocity of the wind on the "Hohe Warte," near Vienna, are collected together in tables α–ϵ in Hoernes' book on *Lenkbare Ballons.* For further details the original papers in the *Jahresberichte der Central-Anstalt für Meteorologie und Elektromagnetismus*, Vienna, may be consulted.

Hoernes found, for example, that at a height of 50–60 m. above Vienna, on the Hohe Warte, during 19·2 per cent. hours a wind blew of more than 8 m. per sec., during 5 per cent. of more than 14 m. per sec., and during 1·5 per cent. of more than

20 m. per sec., these numbers being deduced from readings extending over twenty-six years.

The maximum and minimum for more than 8 m. per sec. of wind were respectively 21·3 and 14·7 per cent. for more than 14 m. per sec., 5·3 and 2·6 per cent. respectively, and for more than 20 m. per sec. 1·5 or 0·4 per cent. respectively hours during a whole year. (For fuller details, see Hoernes' *Lenkbare Ballons, Rückblicke und Aussichten*, Engelmann, Leipzig, 1902.)

6. **The angle of deflection** of the instantaneous direction of the wind from its mean direction often reaches 10° to 20°, or even more, and the difference of the angle of inclination of the momentary wind with respect to the horizontal even in level country may reach 5–6°. See Wellner, Lilienthal, Langley, etc.

7. **In unlimited space** a perfectly regular wind would be without influence on the path of a flying body, since the latter takes up the velocity of the wind, and all calculations relating to lifting power, path, etc., would have to be carried out as if the object were moving in a perfectly calm atmosphere.

8. **With respect to a fixed point** on the earth the following comparisons may be made :—

In the corresponding cases :—

t_1 represents the time,		s_1 the distance,		$v =$	the velocity	in a calm.
t_2	,,	,,	s_2 ,,	$v+u =$	,,	in a favourable wind.
t_3	,,	,,	s_3 ,,	$v-u =$	,,	in an opposing wind.

A_1, E_1, A_2, E_2, A_3, E_3, the corresponding work and power.

Then

$$s_2 > s_1 > s_3$$
$$t_3 > t_1 > t_2$$
$$A_3 > A_1 > A_2, \text{ i.e.}$$

1. The distance covered in unit time by a flying body with an independent forward velocity calculated with respect to a fixed point on the earth is greatest when the body is travelling with the wind and least when travelling against it.
2. The time and work necessary to cover a certain distance are least in a favourable wind and greatest with a contrary wind.

9. **Taking advantage of the various winds.**—The irregularities of the winds are used by birds to aid flight; it is questionable as to whether we may expect to be able to take advantage of such gusts with flying machines.

We attribute the possibility of the circling of eagles, etc., to

ascending currents of air. For kites every wind is a motor, the more powerful the stronger the wind.

Concerning the influence of the winds on the paths of balloons, see Chap. XII., *C.*, also Renard, *Conférence sur la Navigation Aérienne*, and Hoernes, *Lenkbare Ballons, Rückblicke und Aussichten*, pp. 84–93.

CHAPTER XIV.

ON MOTORS.

By HERMANN HOERNES.

INTRODUCTION.

The motors used in flying machines form, along with those used in torpedo boats and motor cars, a special class of machine to themselves, necessitating a separate branch of study and special experiments and trials.

The following motors have been adopted for aeronautical purposes:—

A. Steam engines.
- (α) Reciprocating steam engines.
- (β) Rotary steam engines or steam turbines.

B. Internal combustion engines.
- (α) Gas engines.
- (β) Petrol engines.
- (γ) Benzine engines.

C. Electric motors worked by primary batteries.[1]

These motors set propellers of large superficial area in rapid rotation whereby a large air pressure is artificially produced: a component of this pressure is used to overcome either (1) the head resistance (in air-ships), or (2) the weight (in flying machines).

The conditions which an air-ship motor must fulfil are the following:—

(*a*) The weight of the motor must be as small as possible in proportion to its maximum output.
(*b*) The quantity of fuel used must be a minimum.
(*c*) The motor must run without vibration.
(*d*) The motor must be well governed for varying loads.
(*e*) It must be efficient at varying speeds.
(*f*) It must work reliably for long periods,
(*g*) and automatically under all circumstances.

It is of the highest importance that the engine frame be so designed that the propelling power is transmitted uniformly over the whole framework of the flying machine or airship.

[1] Flying machines have also been devised worked by the aviator himself.

§ 1. UNITS.

A. *Fundamental Units.*

Absolute (physical).	Technical.
System of units.	
Unit of: Length (l) = 1 centimetre. Mass (m) = 1 gram. Time (t) = 1 second.	Unit of: Length (l) = 1 metre (or km.). Force (F) = 1 gram weight (or kg. weight). Time (t) = 1 second (or hour).

B. *Derived Units.*

SURFACE =

Length × Breadth.

$A = a.b.$

Absolute		Technical
$A \equiv$ * l^2	Dimensional equation.	$A \equiv l^2$
$A \equiv$ cm.^{2}	Unit.	$A \equiv$ m^2

VOLUME =

Length × Breadth × Thickness.

$V = a.b.\delta.$

Absolute		Technical
$V \equiv l^3$	Dimensional equation.	$V \equiv l^3$
$V =$ cm.^{3}	Unit.	$V =$ m^3

PATH

Path traversed = velocity × time = path traversed in unit time × time.

$s = l$

Absolute		Technical
$s \equiv l$	Dimensional equation.	$s \equiv l$

* $\equiv$ represents "dimensionally equivalent to."

VELOCITY =

Path per unit time $= \dfrac{\text{Distance}}{\text{Corresponding time}}$.

$$v = \frac{l}{t}$$

$v \equiv lt^{-1}$	Dimensional equation.	$v \equiv lt^{-1}$
$v = \text{cm. sec.}^{-1}$	Unit.	$v = \text{m. sec.}^{-1}$

ACCELERATION =

Increase of velocity in unit time =
Rate of alteration of velocity.

$$f = \frac{v}{t}$$

$f \equiv lt^{-2}$	Dimensional equation.	$f \equiv lt^{-2}$
$f = \text{cm. sec.}^{-2}$ *i.e.* the unit which increases v by 1 cm. per sec. every second.	Unit.	$f = \text{m. sec.}^{-2}$ $g = 9{\cdot}81$ m. sec.$^{-2}$ g varies with the latitude (although only very slightly), and is not an absolute constant. In London $g = 9{\cdot}81$ m. sec.$^{-2}$. At the Poles $g = 9{\cdot}8318$ m. sec.$^{-2}$. At the Equator $g = 9{\cdot}7810$ m. sec.$^{-2}$.

FORCE =

Cause of motion (or of an alteration of position) = Cause of the acceleration of a mass.

The force (F) is proportional to the product of the mass (M) and the acceleration (f).

$$F = Mf = M\frac{v}{t}$$

The unit of force is unit momentum in unit time. It is called a gram (kg.) weight, as distinguished from the mass of a gram. The gram weight is the force which will give a mass of 1 cub. cm. water at 4° C. the acceleration of g. Roughly 1 gram weight = 981 dynes (cm. gm. sec.$^{-2}$).

1 kilogram weight = 981,000 dynes.

$F \equiv lmt^{-2}$	Dimensional equation.	$F \equiv kg.$
1 dyne = 1 cm. × 1 gm. × 1 sec.$^{-2}$. = cm. gm. sec.$^{-2}$. 1 dyne will give a gram mass an acceleration of 1 cm. sec.$^{-2}$.	Unit of force.	F = G.

MASS =

$$\frac{\text{Force}}{\text{Acceleration}} = e.g.\ \frac{\text{grams (weight)}}{\text{acceleration}}.$$

$$M = \frac{F}{f} = \frac{G}{g}$$

A fundamental, not a derived, unit in Physical Science. Since the fundamental unit of mechanics—force—possesses a variable value at different places, the physicist chooses another fundamental unit which has the same value at all places on the earth. This is the gram mass, *i.e.* the mass of a cubic cm. of water at 4° C.

$m \equiv m$	Dimensional equation.	$M \equiv l^{-1}$ kg. t^2
	Unit of Mass.	$M = $ m.$^{-1}$ kg. sec.^{2}
$m = 1$ gram mass		$= \dfrac{\text{kilograms weight}}{\text{metre} \times \text{second}^{-2}}$

PRESSURE =

Force on a surface (per unit area).

$$\sigma = \frac{F}{A}$$

$\sigma \equiv l^{-1}mt^{-2}$	Dimensional equation.	$\sigma \equiv$ kg. l^{-2} $=$ kg. cm.$^{-2}$
	Unit of pressure.	$a = 1$ kg. $\times$ 1 cm.^{2} $= 1$ normal atmosphere.

WORK =

Product of force × displacement in the direction of the force = Kinetic energy, *i.e.* the energy of motion (as distinguished from potential energy, or energy of position, equivalent to the work stored up).

$$W = Fs = \frac{mv^2}{2}$$

$W \equiv l^2mt^{-2}$ Dimensional equation. $W = l$ kg.

Unit of Work.

1 erg = 1 dyne × 1 cm.
= 1 cm.^{2} × 1 gm. × 1 sec.$^{-2}$
10^7 ergs = 1 Joule.

1 m. kg. = 1 Joule (approximately).

POWER or Rate of doing work =

Work per unit time = Force × displacement in the direction of the force, per second.

$$P = Wv = \frac{Fs}{t}$$

$P \equiv l^2mt^{-3}$ Dimensional equation. $P \equiv l$ kg. t^{-1}

Unit power.

1 watt = 10^7 dynes × 1 cm. × 1 sec.$^{-1}$
$= 1 \frac{\text{Joule}}{\text{sec.}}$
$= 10^7$ cm.^{2} gm. sec.$^{-3}$

1 watt = 1 m. kg. sec.$^{-1}$
1 H.P. (metric) = 75 m. kg. sec.$^{-1}$
= 736 watts.
1 H.P. (English) = 746 watts.

Recapitulation.

Name of Dimension.	Dimensional equation.		Unit.	
	Absolute.	Technical.	Absolute.	Technical.
Length . . .	$l \equiv l$		$l = \text{cm.}$	$l = \text{m.}$
Time . . .	$t \equiv t$		$t = \text{sec.}$	$t = \text{sec.}$
Area . . .	$A \equiv l^2$		$A = \text{cm.}^2$	$A = \text{m.}^2$
Volume . . .	$V \equiv l^3$		$V = \text{cm.}^3$	$V = \text{m.}^3$
Path . . .	$s \equiv l$		...	...
Velocity . . .	$v \equiv lt^{-1}$		$v = \text{cm. sec.}^{-1}$	$v = \text{m. sec.}^{-1}$
Acceleration . .	$f \equiv lt^{-2}$		$f = \text{cm. sec.}^{-2}$	$f = \text{m. sec.}^{-2}$ $g = 9{\cdot}81\ \text{m. sec.}^{-2}$
Force . . .	$F \equiv lmt^{-2}$	$F \equiv G$	1 dyne $= \text{cm. gm. sec.}^{-2}$	$F = \text{kg.}$
Mass . . .	$m \equiv m$	$m \equiv l^{-1}\ \text{kg.}\ t^2$	$m = \text{gm.}$	$M = \text{m}^{-1}\ \text{kg. sec.}^2$
Pressure . . .	$\sigma \equiv l^{-1}mt^{-2}$	$\sigma \equiv \text{kg.}\ t^{-2}$	...	$a = \text{cm.}^2\ \text{kg.}$ $= 1$ normal atmosphere
Work . . .	$W \equiv l^2mt^{-2}$	$W \equiv l\ \text{kg.}$	1 erg $= \text{cm.}^2\ \text{gm. sec.}^{-2}$ 10^7 ergs $= 1$ Joule	1 m.kg. $= 1$ Joule (nearly)
Power . . .	$P \equiv l^2mt^{-3}$	$P \equiv l\ \text{kg.}$	1 watt $= 10^7\ \text{cm.}^2\ \text{gm. sec.}^{-3}$	1 HP. $= 75\ \text{m. kg. sec.}^{-1}$ $= 736$ watts.

C. Electrical Units.

Name.	Notation.	Law.	Units.				Remarks.
			Absolute Dimensions.	Practical.			
				Notation.	Name.	In terms of absolute Unit.	
Pole strength	M	$F=\frac{MM_1}{d^2}$	$l^{\frac{3}{2}}m^{\frac{1}{2}}t^{-1}$	...	...	...	
Strength of current	i	$F=\frac{2\pi iM}{r}$	$l^{\frac{1}{2}}m^{\frac{1}{2}}t^{-1}$	Amp.	Ampère	10^{-1}	The number of coulombs of electricity passing the cross section of the conductor in 1 sec. is termed the number of ampères.
Quantity of electricity	Q	$=it$	$l^{\frac{1}{2}}m^{\frac{1}{2}}$	...	Coulomb	10^{-1}	
Electromotive force	E	$=\frac{W}{Q}$	$l^{\frac{3}{2}}m^{\frac{1}{2}}t^{-2}$	...	Volt	10^{8}	1 Volt is the unit of electromotive force, and gives a current of 1 amp. when applied to the ends of a conductor whose resistance is 1 ohm.

Resistance	R	$=\frac{E}{i}$	lt^{-1}	ω	Ohm	10^9	R (in ω) $=\rho\,\frac{l}{A}$ where ρ is the specific resistance, l the length in cm., and A the cross section in sq. cm. of the conductor.
Electric capacity	C	$=\frac{Q}{E}$	$l^{-1}t^2$	...	Farad	10^{-9}	
Electrical work	W	$=Eit$	l^2mt^{-2}	J	Joule	10^7	
Rate of doing electrical work or Power	P	$=\frac{EQ}{t}$ $=Ei$	l^2mt^{-3}	...	Watt	10^7	

Notes.—Specific resistance $\rho = R$, for $l = 1$ cm. and $A = 1$ sq. cm.

,, conductivity $\frac{1}{\rho} = \frac{1}{R}$, for $l = 1$ cm. and $A = 1$ sq. cm.

Coulomb's Law: $F = \frac{QQ^1}{d^2}$.

Ohm's Law: $E = iR$ where E is the potential difference between any two points of a circuit traversed by an electric current, i = the strength of current, and R = the resistance.

Faraday's Law: $Q = kit$.

Joule's Law: $W = i^2Rt = Eit$.

Measurement of effective horse-power.—The effective horse-power is conveniently determined by means of an ordinary friction dynamometer, of which the Prony brake is a good example.

Let H.P. = horse-power developed.
n = the number of revolutions per minute.
W = the effective load in kg.
l = length in metres.

Then $\text{H.P.} = \frac{2\pi n W l}{60 \times 75}$.

§ 2. THE ANIMAL MOTOR.

The rate of working of an ordinary man is approximately 0·1 H.P. This rate can be exceeded during very short periods; for example, for two minute periods a man may develop about 0·3 H.P., and he may even develop 0·5 H.P. for very much shorter periods again.

Experiment has shown that the above powers are quite unsuitable for propelling either air-ships or flying machines of the size necessary to carry the aviator's own weight.

§ 3. ELECTRIC MOTORS.

1. Electric motors are built up of the motor framework, the field magnets, the armature, and the commutator. They are actuated by an electric current furnished either by a dynamo or by accumulators.

2. We may distinguish between direct-current machines (in which the alternating current produced is so commutated and collected that it gives an approximately constant current, flowing in one direction only in the external circuit), and

alternating-current machines (in which the alternating current itself is allowed to flow through the external circuit).

3. Direct-current machines may be divided into two classes: ring-wound and drum-wound machines, according as to whether an anchor ring or a cylinder is wound with wire; each possesses a commutator, which commutates the alternating currents generated in the windings into a direct current in the external circuit.

4. Alternating-current machines have no commutator, since the current does not require to be changed in direction. The coils in which the current is induced either move past fixed magnets (the current being collected by brushes from simple slip rings), or a system of magnets is moved within an anchor ring (the current being led out from fixed terminals). Alternating-current machines are used principally in combination with transformers.

5. The electric motor has attained a high state of development, especially as regards the power developed per weight of machine, high efficiency, simple build, quick, steady, and odourless working, ready reversibility of the direction of rotation, and adaptability to overloads. The rate of revolution can be varied within wide limits. Occupies very little room.

6. In connection with electric motors we may note the following:—

(*a*) The electromotive force of the machine is the total voltage excited in the windings of the armature.

(*b*) The terminal voltage is that between the ends of the armature windings, it is equal to the initial voltage in the external circuit, and is less than the electromotive force excited owing to losses in the armature windings.

(*c*) The strength of current (i_a) in the armature windings.

(*d*) The strength of current (i) in the outer circuit between the terminals.

(*e*) The total power W_a of an electric motor is equal to the product of E_a and i_a or $W_a = E_a i_a$ watts, or since 736 watts = 1 metric H.P., $W_a = \frac{E_a i_a}{736}$ H.P. To find the H.P. (English), substitute 746 for 736.

(*f*) The available electric power for direct currents is equal to the product of E and i or $W = Ei$.

$$W = \frac{Ei}{736} \text{ H.P.}$$

(*g*) For alternating currents: Power $= Ei \cos \phi$ watts, where $\cos \phi$ is the power factor, ϕ being the difference in phase between E and i, or the angle of lag, as it is called.

(*h*) The electrical efficiency is the ratio of the total energy absorbed by the armature to the useful work developed by the armature.

(*i*) The mechanical efficiency is the ratio of the power developed by the armature to the net power (mechanical) developed on the shaft.

(*j*) The commercial or net efficiency is the ratio of the power (electrical) put into the armature to the power (mechanical) developed on the shaft.

7. Stoppages may occur in electric motors from any of the following causes:—

(*a*) Through the failure of the current.

(*b*) Through demagnetisation of the pole pieces.

(*c*) Through entanglement of the wires.

(*d*) Through sparking at the commutator brushes.

(*e*) Through the heating of the armature and field coils above 60 or 70° C., and consequent melting of the insulation.

The total weight of an electrical installation comprises the weights of the dynamos and the driving gear, the accumulators or batteries and regulating resistances and switches, or of the prime mover (*e.g.* steam turbine) and parts, in addition to the weight of the motor itself.

Electric motors were used by Tissandier, and in Renard-Kreb's air-ships (1884–5). The 8·5 H.P. motor used by the latter weighed 654 kg., or, roughly, 77 kg. per H.P. "Les piles légères du ballon la France" are described fully by Renard himself in the *Revue de l'Aéronautique*, 1890, p. 30.

Accumulators are at present so heavy that they can only be used for driving auxiliary motors. Dynamos necessitate the use of so much iron, even in large machines, that they can only be built of great weight (*cf.* Hütte, *Ingenieurs-Taschenbuch*; Weiler, *Die Dynamomaschine*, etc.; Gerhard's *Elemente der Electrotechnik*; *Die Electrotechnik*, by Görges und Zickler, etc.).

§ 4. STEAM ENGINES.

In a steam engine the working material is steam under pressure, furnished by a suitable boiler. We must distinguish between rotary steam engines (or steam turbines) and reciprocating engines.

In a reciprocating steam engine the steam passes into a cylinder, expands, and actuates a piston, from which the power is taken by means of a suitable connecting rod and crank shaft.

Rotary steam engine or steam turbine.—In this the steam,

entering under high pressure, impinges on the blades of a wheel. The expansion is completed between the entrance valve and the mouth of the exhaust. The steam gives up its kinetic energy, which is proportional to its expansion, just as though it had been allowed to expand in the cylinder of a reciprocating engine. This kinetic energy is transferred to the blades of the wheel in the same way as that in which the energy of the water is transferred in a hydraulic turbine. There is, therefore, no to and fro motion, and the velocity remains constant throughout the revolution, whence the absence of vibration, which is one of the great advantages of this type of prime mover.

The entry velocity of the steam is very great (for $a=4$, $v=735$ m. per sec., for $a=10$, $v=892$ m. per sec., in a non-condensing machine, and $v=1070$ or 1187 m. per sec. respectively, in a condensing engine working at a condensation pressure of $\frac{1}{10}$ atmosphere), hence the rate of revolution of the receiving wheel is also very rapid, being between 7400 and 30,000 revs. per min. according to the type of engine—these corresponding to peripheral velocities of from 175 to 400 m. per sec.

De Laval's steam turbine will work under any pressure. The amount of steam used is less the greater the pressure and the more perfect the condenser.

Steam turbines work just as economically as the best-known compound reciprocating engines. The attention necessary is very small, and the work of cleaning need hardly be considered, almost all packing and bolting up being unnecessary.

The quantity of steam used is almost proportional to the load of the turbine, while the simple construction of the machine makes dismounting and overhauling very rapid and easy.

Steam turbines take up very little room. De Laval's turbines, for example, requiring for

	Length.	Breadth.	Height.
20 HP. A space of .	1·350 m.	0·707 m.	0·997 m.
30 ,, ...	1·466	0·707	0·997
50 ,, ...	2·175	0·940	1·237
75 ,, ...	2·604	1·060	1·318
100 ,, ...	2·870	1·320	1·565

Reciprocating steam engines are being built extremely light, at the present day, in the automobile industry. Since it would lead too far to consider in detail, in this book, all the numerous types, only the steam engine used by Maxim will be briefly sketched and the properties of different fuels mentioned.

The most important parts of a steam engine are :

(*a*) The steam generator (a water tube boiler heated by benzene is the lightest in use at the present time).

(*b*) The tubes.
(*c*) The actual engine, including parts.
(*d*) The condenser (with pumps).
(*e*) Vessels for water and fuel.
(*f*) The parts, such as valves, testing taps, water gauge, manometer.

See Uhland, *Handbuch für den praktischen Maschinen-Konstrukteur*; or Haeder, *Dampfmaschinen und Dampfkesseln*; Hütte, *Des Ingenieurs Taschenbuch*; Weissbach, *Ingenieur*; Hrabak, *Dampfmaschinen*; Radinger, *Dampfmaschine mit hoher Kolbengeschwindigkeit*; Reiche, *Transmissions-Dampfmaschinen*, etc.

Maxim's 363 H.P. motor had a total weight, including water, of 545 kg., and the two compound engines belonging to it a weight of 272 kg.

The steam necessary with this was 1·13 kg. per H.P. hour, so that the weight of fuel and feed-water for a whole hour was about 15 kg. per H.P.

The two compound engines were manufactured of steel. Each had a high-pressure cylinder 0·128 m. in diameter, and an expansion cylinder 0·203 m. in diameter, the stroke being 0·305 m. Since the machine at full load worked at 375 revs. per min., the mean speed of the piston was 3·81 m. per sec.

The clearance-ratio in the high-pressure cylinder was 0·75 per cent., and in the low-pressure cylinder, 0·625 per cent. The pressure of steam on admission was at most 22·5 atm., the mean excess pressure in the small cylinder 13·6 atm., and that in the large cylinder 8·7 atm., estimates which are probably too high. On the other hand, however, the theoretical pressure diagrams gave values not much smaller, and the two engines may have produced an indicated H.P. of 450 at the maximum velocity, and also the 363 net H.P.

A diagram of the engine is given on p. 26 of *The Aeronautical Annual*, 1896, and in the *Revue de l'Aéronautique*, 1902. Another light motor was made by Herring; for particulars see *The Aeronautical Annual*, p. 68, 1897.

§ 5. FUEL.

1. **Fuel** is a natural store of energy. This energy is set free on burning, being transformed into heat energy, which can then be utilised for the production of useful work.

The choice of fuel resolves itself into how to obtain the greatest amount of energy from the least weight of material.

2. **The heating effect.**—We must distinguish between—
(*a*) The calorific or absolute heating power.

(*b*) The specific heating power.

(*c*) The calorific intensity or pyrometrical heating power.

(*a*) The absolute heating power (heat of combustion) of a fuel is the number of heat units (calories) which are developed by the combustion of unit weight (1 kg.) of the same.

(*b*) The specific heating power of a fuel is the number of heat units developed by the combustion of unit volume (1 litre) of the same.

(*c*) The pyrometrical heating effect of a fuel is the temperature measured in centigrade degrees which would be attained if the combustion took place using exactly the right amount of oxygen, and no loss of heat occurred.

3. **The heating power** (calorific).—On account of incomplete combustion only 70–90 per cent. of the full heating power is available. The absolute heating power measured in calories with complete combustion is for: Charcoal, 7500; coal, 7000–7800; paraffin, 9000; petroleum, 11,000; ether, 9028; alcohol, 7184; olive oil, 11,200; marsh gas, 13,346; H_2 to H_2O (vapour), 28780; H_2O (liquid), 34,180–34,462.

4. Air necessary for combustion, about 10–18 times the weight of material burnt. The temperature of combustion increases with the amount of air available, hence we use warm air and artificial draughts.

5. **Heating surface.**—Any surface covered by the water to be evaporated. The communication of heat from the fuel to the feeding water takes place through the heating surface, directly by the radiant heat and indirectly by conduction. The size of the heating surface influences—

(*a*) The production of steam.

(*b*) The economy of the process (enormously).

The area of the heating surface may be roughly estimated as follows:—The I.H.P. × 0·6 gives the heating surface in square metres required. For very high steam pressures the numerical factor is somewhat smaller.

6. The ratio of heating surface to grate area varies widely in different boilers. In boilers of the Lancashire or Cornish type, the ratio lies between 15 and 25, in marine boilers between 25 and 50, and in locomotives it may be as high as 75. The higher the proportion of heating surface the higher is the evaporative efficiency up to a certain limit. With forced draughts a greater extent of heating surface is necessary than with ordinary draughts.

7. The evaporative power of a fuel is the number of kg. of water at 0° C. which 1 kg. of the fuel will convert into steam at 100° C.

8. **Classification of fuels.**—(*a*) Solid, (*b*) liquid, (*c*) gaseous.

(*a*) Wood, peat, coal, coke, etc., all too heavy for air-ships. Coal-dust fuel is best (gives 65–70 per cent. efficiency, and burns without smoke).

(*b*) The distillation products of raw petroleum—petrol and benzine. We may distinguish between—

(α) Light distillation products (coming off below 160°), benzine, petroleum ether, gasoline, ligroine.

(β) Petroleum (b.p. 170–300°).

(γ) Mineral oils and vaseline (above 300°), naphthol; difficult to use. Require special pulverisator and special precautions in firing.

(*c*) Natural gas, coal gas, producer gas, water gas.

9. **Petroleum.**—Specific gravity, 0·77–0·83.

Temperature of ignition between 500 and 600° C.

The consumption of oil per H.P. rises 50 per cent. on an average at half load. Running light, the consumption of petroleum is on an average = 45–60 per cent. of that necessary to run the fully-loaded machine. Mean efficiency of a petroleum engine $\eta = 0·13$, falling rapidly with diminishing load. 1 H.P. hour costs 1–1·2d.

Quantity necessary per H.P. hour not more than 0·45 kg.

Disadvantages: difficult to mix with atmospheric air; imperfect combustion, and hence residues left, necessitating thorough cleansing; unburnt petroleum injures the motor; burns with a dangerous flame and gives off an unpleasant odour.

10. **Benzine** distilled at from 80–100° C.; specific gravity at 15° = 0·68 to 0·70. A cubic metre weighs 680–720 kg., and evaporates very rapidly even at normal temperatures, forming an explosive mixture with air; a suitable mixture for explosion can therefore be obtained by merely drawing air through the benzine liquid. Absolute heating power of 1 kg. benzine, 10,500 to 11,000 calories. The greatest precautions must be taken against fire when using this material. Quantity necessary per H.P. hour 0·35–0·45 kg., giving 3500–6000 calories. Actual efficiency $\eta = 0·14–0·18$, falling with diminishing load. We can get 2·86 H.P. hours from 1 kg. benzine, as against 16 H.P. hours theoretically possible. A 6 H.P. motor requires 330·5 gm. benzine per H.P. hour. The danger of fire is almost eliminated by electrical ignition in gas-tight vessels. 100 litres benzine cost about 30–50s. 1 H.P. hour costs about 2·1d.

11. **Methylated spirits.**—Calorific power of 90 per cent. denaturalised alcohol of specific gravity 0·84 = 5650 calories per kg. For unit power we require, therefore, 1·8 times the weight of spirit as compared to that of lamp petroleum. Spirit is, however, less viscous and burns more completely, hence the

consumption per H.P. hour is only 0·85 kg. A 6 H.P. motor required 758·89 gm. spirit per H.P. hour in an automobile race from Paris to Roubaix. 100 litres spirit cost about 25s. 1 H.P. hour costs about 1·4d.

12. **Coal gas.**—Has on an average a heating power of 5000 calories per cubic metre. We require usually 0·6–0·7 cb. m. per H.P. hour (for 1–10 H.P. engines) or 0·55–0·6 cb. m. (for 10–50 H.P. engines), but for still larger engines the rate of diminution per H.P. is not quite so great. The lowest authenticated consumption of gas is 0·40 cubic metre per H.P. hour, giving an efficiency of $\eta = 0{\cdot}18$–$0{\cdot}31$. For a decrease of load to $\frac{3}{4}$ or $\frac{1}{2}$, the consumption of gas per H.P. rises 10–15 per cent. or 30–35 per cent. resp. The temperatures of ignition for mixtures of 8, 9, and 10 per cent. coal gas with 92, 91, 90 per cent. air were 752, 755 and 765° C. resp., according to Professor Kunte of Carlsruhe.

§ 6. STEAM.

1. The feed water must be taken in in a chemically pure condition, and hold nothing in a state of mechanical suspension. It is therefore necessary in air-ships to have arrangements for the purification of the water. No trouble arises, therefore, from boiler incrustations or fur in the case of air-ship engines, which advantage has, however, the drawback that the cost of the water becomes very great.

2. For every steam engine the total necessary water required per hour must be determined. The feed-water pump must be able to supply 2·2 times this amount. The amount may be calculated from the formula:

$$\frac{\pi}{4} d^2 h = \frac{2{\cdot}2S}{60 n \phi}$$

where S = the quantity of feed-water.
d = the diameter of cylinder.
h = the length of stroke.
n = the number of revolutions per minute.
ϕ = the efficiency of the pump (usually about 0·8).

3. **The steam.**—The source of power in a steam engine is the expansion of the steam. The steam is obtained by heating the water in boilers with non-conducting covering. In air-ships only water-tube boilers are employed.

4. **Steam boilers.**—For air-ships light compact boilers are required, producing steam rapidly at high pressures.

For the production of x kg. steam we require a heating

surface H (if we assume that 19 kg. steam can be produced per sq. m. heating surface) of

$$H = \frac{x}{19} = 0 \cdot 0526 x.$$

$$\text{or } H = 0 \cdot 0526 \text{ V}\gamma.$$

A boiler which, for example, will produce $x = 500$ cb. m. steam at $a = 8$ atmospheres pressure, requires (since 1 cb. m. steam at this pressure weighs $\gamma = 4 \cdot 028$—see Fliegner's Tables) a heating surface of 102·4 sq. m., according to the equation :

$$H = 0 \cdot 0526 \text{ V}\gamma = 0 \cdot 0526 \times 500 \times 4 \cdot 028 = 102 \cdot 4.$$

The thickness of the walls of the heating and fire tubes is (according to Fairbaire) given by $\delta = 1 \cdot 23\sqrt{l.d.a}$ in millimetres, where l is the length in metres and d the diameter in metres.

5. The boiler fittings are :

1. Two feed pipes.
2. Two main steam pipes.
3. Two blow-off cocks.

} Tubes leading to corresponding valves.

4. Two gauge glasses.
5. The pressure gauge (giving the steam pressure in atmospheres).
6. The safety valve.
7. The manhole.

(See Haeder, *Bau und Betrieb von Dampfkesseln.*) Here also it would lead too far to consider the various systems of boilers, and we will take as our single example Maxim's simple, compact, and efficient boiler, designed for his flying machine.

6. Maxim's steam generator, designed on the principle of the Thornycroft boiler, was built out of copper tubes 10 mm. in diameter, with walls 0·5 mm. thick, tested to stand a pressure of 156 atm. Since the heating surface was 74 sq. m., which, with such thin surfaces, could easily yield the steam required (55 kg. per 1 sq. m.), tubes of a total length of 2400 m. were necessary, weighing only 0·13 kg. per m., making the total weight of the tubes 312 kg., the total weight of the boiler being 550 kg.

The fuel used was benzine, which was previously pumped into a small vertical boiler in which it was evaporated ; the pressure in this boiler was kept constant at 3·5 atm. by an automatic regulating apparatus. 7650 burners were used, the burning proceeding quite regularly, the air being blown in by an injector worked by superheated steam, the amount of air, as also the feed-water, being accurately regulated.

Regarding steam we may note :

7. **Ebullition.**—When a liquid boils, the boiling-point (at which the ebullition commences) rises with the pressure exerted on the liquid (see Fliegner's Tables). The pressure

(measured usually in atmospheres excess pressure), temperature, and weight of the steam alter simultaneously and in the same manner.

8. **Kinds of steam.**—Wet, saturated, and superheated steam. In wet steam there are unevaporated droplets of water still left, *i.e.* all the water is not completely evaporated.

In saturated steam no more evaporation of the water can take place, *i.e.* the vapour mixed with the water has attained its maximum pressure for the corresponding temperature. The slightest cooling brings about condensation.

9. **Saturated steam** loses as a rule about 0·5 atm. in pressure on its way from the boiler to the cylinder of a ship's engine, on account of the fall in temperature in the pipes, arriving in the cylinder, therefore, saturated and wet.

A mass of steam saturated at a given temperature may be raised to a higher temperature without any alteration of volume, but is then no longer saturated.

If the temperature of saturated steam is lowered, some of it will condense, thereby diminishing the pressure, although the steam remains saturated. If we allow a given volume of saturated steam to expand, and keep the temperature constant by the addition of heat, the steam ceases to be saturated, its pressure and density are smaller than those corresponding to its temperature, and it behaves, in fact, like superheated steam.

10. Saturated steam is, *à priori*, dry steam, while wet steam is a variable mixture, whose composition is determined if the ratio of steam and water present is known.

It is very difficult, if not quite impossible, to maintain saturated steam dry.

11. **Superheated steam** is free from water. After the last particles of water have been evaporated the supply of heat is continued, so that the temperature is higher than that of saturated steam of the same density.

12. **Temperature of ebullition.**—The boiling-point depends on the pressure. Under normal atmospheric pressure mercury boils at 360° C., linseed oil at 316°, sulphuric acid at 310°, sulphur at 299°, phosphorus at 290°, water at 100°, alcohol at 78·6°, and ether at 37·8° C.

13. **Latent heat of evaporation.**—To convert 1 kg. of any liquid into vapour a certain quantity of heat is needed, differing for different liquids.

14. Let q = the heat stored up in the liquid, *i.e.* the heat necessary to raise 1 kg. water from 0° to $t°$, the temperature of the steam.

15. r = the latent heat of vaporization, *i.e.* the heat necessary to convert 1 kg. water at $t°$ into steam at $t°$, the temperature of ebullition.

The latent heat of evaporation of water (at 100° C.) = 540 cals.
,, ,, ,, alcohol = 208 ,,
,, ,, ,, ether = 98 ,,
,, ,, ,, acetic acid = 102 ,,
,, ,, ,, turpentine oil = 69 ,,

16. J = heat stored up in the steam, *i.e.*, the heat necessary to turn 1 kg. water at 0° into steam at $t°$, assuming no alteration in volume to occur.

17. ρ = internal latent heat = internal energy corresponding to the alteration of condition or state.

18. Apu = external latent heat = heat equivalent of the external work overcome in the evaporation (at constant pressure).

19. λ = the total heat, *i.e.* the heat required to convert 1 kg. of water at 0° C. into steam at $t°$ C., which is equal to the heat stored up in the liquid plus the latent heat of evaporation.

$$\text{Total heat}\left\{\begin{array}{l}\left.\begin{array}{l}\text{heat in liquid}\\ \quad\text{plus}\\ \text{internal latent heat}\end{array}\right\}\text{ Heat in steam.}\\ \quad\text{plus}\\ \text{external latent heat}\end{array}\right.$$

Pressure of steam. In atmospheres (or kg. per sq. cm.)	Pressure of steam. In mm. of mercury.	Temperature in ° C.	Heat stored up in liquid q.	Internal latent heat ρ.	External latent heat Apu.	Spec. volume s in cb. m. per kg.	Density γ = weight of 1 cb. m. in kg.
1·0	735·5	99·09	99·58	497·05	40·10	1·7493	0·5717
2·0	1471·0	119·57	120·37	480·78	41·82	0·9128	1·096
3·0	2206·5	132·80	133·85	470·30	42·85	0·6237	1·603
4·0	2942·0	142·82	144·10	462·38	43·58	0·4760	2·101
5·0	3677·5	150·99	152·48	455·92	44·16	0·3860	2·590
6·0	4413·0	157·94	159·63	450·42	44·63	0·3253	3·074
7·0	5148·5	164·03	165·89	445·62	45·02	0·2814	3·553
8·0	5884·0	169·46	171·49	441·32	45·37	0·2483	4·028
9·0	6619·5	174·38	176·58	437·43	45·67	0·2223	4·499
10·0	7355·0	178·89	181·24	433·87	45·95	0·2013	4·967
11·0	8090·5	183·05	185·56	430·58	46·19	0·1841	5·432
12·0	8826·0	186·94	189·59	427·51	46·42	0·1696	5·895
13·0	9560·5	190·57	193·38	424·63	46·62	0·1574	6·355
14·0	10297·1	194·00	196·94	421·92	46·81	0·1468	6·813

20. Steam does work on expansion.

The expansive force p of saturated steam depends on its temperature, and may be calculated by different empirical formulæ. For pressures of from 1–4 atm. experiments have given:

$$p=\left(\frac{75+t}{175}\right)^6 \text{atm.}$$

or

$$t=175\sqrt[6]{p}-75^\circ \text{ C.}$$

For pressure above 4 atmospheres the following formula holds:

$$p=\left(\frac{39{\cdot}8+t}{139{\cdot}8}\right)^5 \text{atm.}$$

or

$$t=139{\cdot}8\sqrt[5]{p}-39{\cdot}8^\circ \text{ C.}$$

21. The pressure of superheated or unsaturated steam follows from Mariotte-Gay-Lussac's Law, where:

$$\frac{p}{p_1}=\frac{1+0{\cdot}00367\,t\,V_1}{1+0{\cdot}00367\,t_1V}.$$

22. The pressure of saturated steam increases approximately in geometrical progression when the temperature increases in arithmetical progression.

Pressure at	50° mm.	100° mm.	150° mm.	200° mm.
For saturated water vapour,	92	760	3580	11695
,, ,, alcohol ,,	220	1695	7258	...
,, ,, ether ,,	1270	4955	...	...

It is much more economical to work at high steam pressures than at low ones.

23. All gases differ more or less from the ideal gas which exactly obeys the law $pv=RT$. The gases which differ most from it are those gases which condense at relatively high temperatures, and which we call vapours.

24. In the quantity Apu, $A=\frac{1}{424}$ the heat equivalent of the unit of work (metre-kg.), p is the pressure, and u is the difference in the specific volumes (volumes of 1 kg.) of water and vapour, *i.e.*

$$u=s-\sigma$$

where s = the specific volume of the vapour
σ = ,, ,, ,, water.

25. We have the following fundamental equations :

$$\begin{aligned} \lambda &= q + \mathrm{A}pu + \rho \\ r &= \lambda - q \quad = \rho + \mathrm{A}pu \\ \mathrm{J} &= q + \rho \quad = \lambda - \mathrm{A}pu. \end{aligned}$$

Experiments have shown that

$$\begin{aligned} q &= t + 0{\cdot}00002t^2 + 0{\cdot}0000003t^3 \\ \lambda &= 606{\cdot}5 + 0{\cdot}305t. \end{aligned}$$

Whence, since $r = \lambda - q$

$$r = 606{\cdot}5 - 0{\cdot}695t - 0{\cdot}00002t^2 - 0{\cdot}0000003t^3.$$

It has been further found that

$$\rho = 575{\cdot}4 - 0{\cdot}791t \text{ approximately}$$

and

$$\mathrm{A}pu = 31{\cdot}1 + 96t - 0{\cdot}00002t^2 - 0{\cdot}0000003t^3.$$

26. **Quantity of steam necessary.**—The quantity of steam necessary per H.P. hour depends principally on the power of the engine, the admission pressure p, the clearance S, and the terminal pressure.

The steam necessary per hour can be calculated numerically from the following formula given by Hrabak (see Reiche, *Dampfmaschine*, p. 42).

For heated cylinders

$$\mathrm{S} = 0{\cdot}40\gamma c\mathrm{F}\,\frac{\sigma + s_1}{s}.$$

Where

$\mathrm{F} = \dfrac{75\mathrm{N}}{\eta p^i c}$ the cross section of the cylinder in square centimetres.

$c = \sqrt{p_v}$ = the mean speed of the piston in m. per sec.

s = the piston stroke in metres.

s_1 = the piston stroke in m. during the full pressure period.

$\sigma = \dfrac{\text{clearance space}}{\text{cross section of the cylinder.}}$

p_v = Maximum pressure in the cylinder behind the piston.

η = Efficiency of the engine.

27. The total consumption of steam in an engine is made up of the steam usefully employed and the steam lost.

(*a*) The useful consumption in kg. per hour in a single cylinder engine is given by :

$$\mathrm{Q}^1 = 3600\mathrm{O}c\left\{\left(\frac{\mathrm{S}_1}{\mathrm{S}} + m\right)\gamma - 1{\cdot}1\left(1 - \frac{\mathrm{S}_2}{\mathrm{S}} + m\right)\gamma^1\right\},$$

where γ and γ^1 are the weights of 1 cb. m. of the steam

at admission and exhaust respectively; with the aid of the equation—

$$N_i = \frac{10000}{75} Ocp_i,$$

whence we get for the useful consumption per indicated H.P.-hour (C_i^1).

28. $$C_i^1 = \frac{Q^1}{N_i} = \frac{27}{p_i} \left\{ \left(\frac{S_1}{S} + m\right)\gamma - 1\cdot1\,(1 - \frac{S_2}{S} + m)\gamma^1 \right\}.$$

(*b*) The waste of steam arises principally from the cooling inside the cylinder, and to a smaller extent owing to leakages.

29. The numerical calculation of the waste steam is very difficult, and cannot be determined on purely theoretical grounds.

§ 7. CONDENSATION.

1. A body may lose heat both by radiation and convection, the rate of cooling being proportional to the area of the cooling surface. The rate of cooling is measured by the quantity of heat escaping per unit surface in unit time. If the area of the cooling surface is A, then the total quantity of heat escaping per unit time:

$$W = W_1 + W_2.$$

2. The heat radiated is:

$$W_1 = u_1 a^t (a^\theta - 1) A,$$

where $a = 1\cdot0077$, t is the temperature, on the absolute scale, of the surrounding space, t_1 that of the cooling body, $\theta = t_1 - t$, and u_1 is a coefficient of radiation depending on the nature of the radiating surface.

The heat lost by convection is:

$$W_2 = u_2 \theta^{0\cdot233} A,$$

where u_2 is a coefficient of convection depending on the form of the cooling body. The powers $1\cdot0077^t$, $1\cdot0077^\theta$ and $\theta^{0\cdot233}$ may be taken from the table on next page.

If the cooling surface A is measured in square metres, and the unit of time is taken as 1 hour, then the following values may be assumed for u_1:

For polished iron,	$u_1 =$	56·3
,, copper,	,, =	19·9
,, polished brass,	,, =	32·2
,, ,, silver,	,, =	16·2
,, glass,	,, =	362·9
,, lampblack,	,, =	500·0
,, water,	,, =	662·4

Temperature θ degrees.	$1{\cdot}0077^{\theta}$	$\theta^{0{\cdot}233}$	Temperature θ degrees.	$1{\cdot}0077^{\theta}$	$\theta^{0{\cdot}233}$
10	1·080	1·710	110	2·235	2·990
20	1·165	2·010	120	2·510	3·051
30	1·259	2·209	130	2·711	3·108
40	1·359	2·362	140	2·927	3·163
50	1·467	2·488	150	3·160	3·214
60	1·584	2·596	160	3·412	3·263
70	1·711	2·691	170	3·684	3·309
80	1·847	2·776	180	3·978	3·353
90	1·994	2·853	190	4·295	3·396
100	2·153	2·924	200	4·637	3·437

3. Air-ships which remain aloft for long periods are not in a position to renew the feed or cooling water, and they must take with them a certain quantity in a perfectly pure condition at the beginning of the voyage; this has to suffice until the next landing-place is reached. This necessitates the steam being condensed on the air-ship itself.

In large air-ships air condensers are used. These consist of a system of tubes with relatively large surfaces, which are swept against by the air so that the steam within them is cooled sufficiently to condense it. The data of different experimenters on the efficiency of air-condensers are very varied in character.

4. According to Grashof (in an article on steam heating) the necessary surface A, to carry away a given quantity of heat W, is given by $A=\frac{W}{12(t-\Delta)}$, where t is the temperature of the steam, and Δ the mean temperature of the air.

$$\text{If we put } \left\{ \begin{array}{l} t=110^{\circ} \\ \Delta=14, \end{array} \right\} \text{ then } A=\frac{W}{1152}.$$

For steam at atmospheric pressure and air at 28°, 1·6 kg. of steam would be condensed per sq. m. per hour.

5. Wenham proposed, at the Aeronautical Club in London, the use of an air-injector condenser. He proposed to force air by means of a fan into the exhaust chamber.

Disadvantage.—The air must find its way into the open again, and carries water with it and will not maintain a vacuum, but only produce a partial recovery of the back pressure.

6. Perkins (*Engineering*) condensed 1 62 kg. steam per sq. m. per hour, but required about one-eighth of the total power of

the steam engine to do it. Tomlinson thought that at least half the steam escaped into the air during the process.

7. Popper states that the spontaneous cooling effect of air for tubes lying horizontally is almost exactly twice as great as for tubes placed vertically, since in the first case there are a whole series of currents set up, while in the second case there is only one upward current of air produced. At $t=20°$ in a horizontal position two-thirds of a kg., and in a vertical position one-third kg., of steam were condensed per sq. m. per hour. If, however, the vertical condenser was cooled by a small fan, 3 to 3½ times as much steam was condensed, namely 1·2 kg. or more per sq. m. per hour. The use of bellows for air cooling or of large flat surfaces, which are cooled by air striking them parallel to the surface, has not been found practical. It is best to cool the steam directly by means of the air currents produced.

In gradually increasing the velocity of the cooling air a limit in the gain in cooling power as compared to the expenditure of work is soon reached.

In one experiment the area of a Popper condenser was two-thirds of a sq. m. It consisted of 144 tubes each 10 mm. in diameter. Without any artificial draught 0·6–0·66 kg. steam per sq. m. per hour was condensed, the temperature of the air being 15–16° C.

On using a fan the amounts condensed were for :—

$n=$	360–400 revs. per min.	1·044	kg.	Temp. at exit,	65° C.
,,	630 ,,	1·15	,,	,, ,,	62° C.
,,	1260 ,,	1·8	,,	,, ,,	58° C.
,,	1400 ,,	2·0–2·25	,,	,, ,,	43° C.

A pressure fan was found to be less efficient for condensing purposes than a vacuum fan in the ratio 1·22 : 1·7, *i.e.* it is better to suck the air through the condenser than to force it through.

8. Daimler has attached to his motor an air condenser, consisting of a thin metal drum, through which a large number of parallel thin and thin-walled tubes are passed, between which the steam passes. At the back is a fan which serves to suck the air through the tubes.

§ 8. INTERNAL COMBUSTION ENGINES (GAS AND OIL ENGINES).

1. The combustion in these engines may take place suddenly (under constant volume), as in an ordinary gas and oil engine, or under constant pressure, as in the Diesel engine.

2. The **petrol motor** has reached a very high state of efficiency in connection with the motor-car industry, and in the meantime appears to be the only available prime mover for air-ships or flying machines. One looks, however, for an improvement in the form of a light electric motor.

3. **Principle of action.**—Four-stroke Otto cycle.—The explosive mixture may consist of gas and air, or oil vapour and air, which, when exploded, produces a force directly on the piston. The motion of the piston is converted by means of a connecting rod and crank in the usual manner into a rotary motion.

(1) Drawing in the mixture during one whole stroke of the piston.

(2) Compression during the return stroke (into a comparatively large clearance space below the piston).

(3) Ignition at the dead point, followed by expansion during the third stroke.

(4) Discharge of the burnt gases from the cylinder during the fourth and last (scavenging) stroke.

This "four-stroke" cycle of operations is now used in almost all gas and oil engines. An engine having an impulse every two strokes is also used, but so far experience has favoured the adoption of the four-stroke engine. For the details of the two-stroke motor resource may be had to the usual text-books on the subject (see below).

4. **Principal parts of the four-stroke cycle engine.**

(*a*) Frame.
(*b*) Cylinder, with piston, connecting rod, and crank-shaft.
(*c*) Carburetter.
(*d*) Igniter or sparker.
(*e*) Valves and governors.
(*f*) Cooling arrangements.
(*g*) Lubricating arrangements.

(*a*) *Frames.*—The frames usually consist of channel iron, which has great stiffness in comparison with its weight. Magnalium is occasionally used on account of its lightness.

(*b*) Single-cylinder engines of the vertical type are preferable to those of a horizontal type, and are in general the only ones in use for aeronautical work.

It is essential to have the engine as well balanced as possible. This is attempted in various ways.

When the cylinders can be arranged to do away with balance weights a corresponding saving in the weight of the engine is obtained. By having three or four cylinders the motion is more regular and the engine is more completely balanced. Four- and six-cylinder engines are rapidly displacing those having fewer cylinders at the present time.

(*c*) The *carburetter* is the apparatus in which the petrol is

vaporised. The petrol is either forced by air pressure into the carburetter, or the petrol tank is placed higher so as to ensure a gravity feed.

A constant height of petrol is maintained in the float chamber by means of a needle valve which passes through a tube in the float. Many devices have been introduced to ensure the pulverisation of the petrol by causing it to impinge against serrated cones and perforated diaphragms (see Text-books for details of carburetters). The vaporised gas gets thoroughly mixed with the incoming air before entering the cylinder.

All carburetters should have a heating jacket round the mixing chamber, as the intense cold caused by the evaporation freezes the moisture in the air and so chokes up the working parts. As a rule heated air obtained from the vicinity of the exhaust pipe is used for this purpose.

(*d*) *Ignition.*—The system in general use is known as the high-tension system. To obtain the spark at a firing plug the current is conducted through a make-and-break device fitted on the half-time shaft of the motor. This device consists of a ring of wood fibre into which metal strips are fitted, having terminals to which storage cells are wired. The current is then conducted through the induction coil, fitted with trembler blades, and from it to the sparking plug, the circuit being completed through the engine. This system requires little attention beyond being kept clean.

Magneto ignition is now coming greatly into use, a better spark being obtained. A shield having slots cut in it is mounted between the magnet and the armature, and is made to oscillate by means of a small crank or eccentric on the engine shaft. The shield interrupts the lines of force from the magnet, and as it oscillates the current is alternately made and broken, the current being conducted to a make-and-break device in the cylinder head.

(*e*) The inlet valve is worked entirely automatically, whereas the exhaust valve is operated mechanically.

(*f*) We may distinguish between air and water cooling.

Air cooling is accomplished by providing a large area of cooling surface. A fan is used to bring air in contact with the cooling surface.

Water cooling, however, is more efficient. The water after passing through the cylinder, where it gets heated, is led through a radiator, which is designed to have a very large cooling surface. The water is preferably pumped through its circuit. The thermo-syphon system is also adopted, and has proved very efficient.

It is essential that the walls of the cylinder be kept cool, otherwise the efficiency falls.

(*g*) *Lubricating.*—Excellent results have been obtained from the splash system, fed from a side-feed lubricator, which can be set to give any number of drops per minute. Pipes are led to the main bearings and also to a position so as to drop oil on to the connecting-rod ends.

5. The principal considerations in the design of an internal combustion engine suitable for air-ships are :—

(*a*) Reliability.
(*b*) Small weight per unit of power.
(*c*) Absence of vibration.

6. In order to get an engine of small weight to develop a given H.P., it is essential that the speed be very great. Modern petrol engines run successfully at speeds from 1000–1500 revs. per min. These engines have been running for years without any sign of undue wear.

A petrol engine running at 1500 revs. per min., and having a stroke of 120 mm., has a piston speed equal to $\frac{ns}{30} = \frac{1500 \times \cdot 12}{30} = 6$ metres per second.

A petrol engine having a $1\frac{1}{8}$-inch nickel-steel crank running at 1500 revs. per min. has a bearing surface speed $= \frac{3 \cdot 53 \times 1500}{12}$ $= 441$ ft. per min.

The above speeds are well within those reached by a modern locomotive going at sixty miles an hour.

7. In four-stroke cycle motors the H.P. is given by the formula :

$$N_e = \frac{p \cdot \frac{\pi d^2}{4} \cdot s \cdot n}{60 \times 75 \times 2} \text{ H.P.},$$

where d = diameter of piston in metres,
s = the piston stroke in metres,
N_e = the effective power in H.P.

Text-books.—*A Practical Treatise on Modern Gas and Oil Engines*, by Frederick Grover. Manchester : The Technical Publishing Co., Ltd. *The Steam Engine and Gas and Oil Engines*, by John Perry. London : Macmillan & Co. *The Gas and Oil Engine*, by Dugeld Clerk. London : Longmans & Co. *Gas and Oil Engines*, by Brigan Donkin London : Griffin & Co.

CHAPTER XV.

ON AIR-SCREWS.

BY MAJOR HERMANN HOERNES.

§ 1. CLASSIFICATION OF AIR-SCREWS.

A SCREW-PROPELLER is built up usually of two or more blades. Each blade may be regarded as a small portion of the thread of a screw of great pitch, and of considerable depth relatively to the pitch.

(*a*) *According to their construction.*

Simple Screws.—The blades are arranged on the circumference of the boss.

Multiple Screws.—The blades are fastened along a shaft at certain distances from one another.

They may also be attached to separate shafts placed in parallel, in which case they are simple multiple screws.

$\left.\begin{array}{r}\text{Single-}\\ \text{two-}\\ \text{three-}\end{array}\right\}$ bladed screws, according to the number of blades on the simple screws.

$\left.\begin{array}{r}\text{Single-}\\ \text{two-}\\ \text{three-}\\ n\text{-}\end{array}\right\}$ bladed multiple screws, if there are one, two, three or n blades on each shaft.

$\left.\begin{array}{r}\text{Single-}\\ \text{two-}\\ \text{three-}\\ n\text{-}\end{array}\right\}$ bladed m rowed multipled screws, if there are simple, two, three or n bladed screws on m shafts.

$\left.\begin{array}{r}\text{Right-}\\ \text{Left-}\end{array}\right\}$ handed screws, according as the screw conforms with a right- or left-handed helix.

(*b*) *According to their action.*

$$\left.\begin{array}{l}\text{Lifting}\\ \left.\begin{array}{l}\text{Driving}\\ \text{Pressure}\end{array}\right\}\\ \text{Universal}\end{array}\right\}\ \text{screws}\ \left\{\begin{array}{l}\text{with a vertical}\\ \text{with a horizontal}\\ \text{with an inclined}\end{array}\right\}\text{axis.}$$

§ 2. GEOMETRICAL ELEMENTS.

The helix.—The trace of a point moving uniformly round a cylinder, at the same time ascending at a uniform rate.

Let l = length of helix,
d = diameter of cylinder,
h = height of cylinder,

then $l=\sqrt{\pi^2 d^2+h^2}$.

The pitch of the screw.—Rise in one complete turn, or the distance through which it would advance in one complete revolution, provided it revolved in an unyielding medium such as a solid nut.

To draw the helix.—Divide the circumference of the cylinder in plan and also the pitch in elevation into n equal parts. The points of intersection of vertical and horizontal lines through corresponding points lie on a helix.

The triangle of pitch is formed by the developed pitch line for one complete revolution of the screw as hypothenuse, the developed circumference and the pitch as the base and perpendicular respectively.

The screw surface is obtained by the progressive rotation of a straight or curved line on a screw line or helix.

Plane of projection.—The plane perpendicular to the axis of the screw.

Planes of axis.—The planes passing through and including the axis.

Right screw surfaces are obtained when the generating line is perpendicular to the axis.

Inclined screw surfaces are obtained when the generating line is inclined acutely to the axis.

Axis of screw.—The straight line about which the generating line is moved.

§ 3. THE BLADES.

The blades of the screw form a fraction of the whole screw surface.

Right-handed screws.—The screw thread runs along the axis from left to right, from below to above, seen from above.

Left-handed screws.—The screw thread runs from right at the bottom to left at the top, seen from above.

(Trade and French ships have right-handed propellers, warships, except the French, left-handed propellers.)

Vertical distance of the screws.—The broader and longer the blades, the greater the pitch, the greater the angular velocity and the wider apart the screws must be; the distance depends

on the generating line and on the arrangement of the screw surfaces.

Number of blades.—Fixed by the pressure required.

Size of blades.—Must be determined by experiment.

Spacing of blades.—At 90°, 120°, or 180°.

Area swept out by blade per revolution, $F_k = \frac{\pi}{4}(D^2 - d^2)$, D being the diameter of the screw (*i.e.* the diameter of the circle formed by the tips of the blades when revolving) and d the diameter of the boss.

Projected screw surface.—The surface of the blades projected into one plane (perpendicular to the axis).

Forms of blade surfaces.—Trapeze-shaped (old), sector, quadrilateral, triangular, etc.

The shape influences the propulsion, friction, and the formation of eddies.

The ratio of the actual area of the whole blade surfaces of the screw, to the whole area of one complete pitch of the screw surface, is termed the fraction of the screw area f_t.

The ratio of the area of one blade surface, to the whole area of a complete pitch of the screw surface, is termed the partial fraction of the screw area f_e.

$$f_e = \frac{f_t}{2},\ \frac{f_t}{4},\ \text{etc.}$$

Length of blade: $l = \frac{D - d}{2}$,

Total length of blades $= il$, where i is the number of blades.

Strength of blade (h), its greatest thickness.

If P = thrust on the circumference in kg.,

δ = diameter of the shaft,

γ_1 = the modulus of rigidity in the shaft,

$$\frac{P.D}{2} = \frac{\pi}{16}\delta^3\gamma_1 ;$$

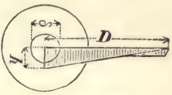


FIG. 139.

and if b = length, and h the depth of the cross section, γ = Young's modulus, i = number of blades.

$$\frac{PD}{2} = \frac{\pi}{32} ibh^2\gamma,$$

$$\text{whence} \qquad h = \sqrt{2\frac{\gamma_1}{\gamma} \cdot \frac{\delta^3}{ib}}.$$

Nave of screw.—Cylindrical, conical, or wheel-shaped.

Material.—Steel, aluminium, magnalium, etc.

Strength.—The length and diameter must be determined by the theory of structures.

Method of attaching the blades.—By welding on plate-shaped discs and screws.

§ 4. THE DIAMETER OF THE SCREW.

1. The dependence of diameter on the number of turns
2. The dependence of diameter on the work
3. The dependence of diameter on the blade area
4. The dependence of diameter on the surface resistance
5. The dependence of diameter on the displacement resistance
6. The dependence of diameter on the number of vibrations per second
7. The dependence of diameter on the weight of screw
8. The dependence of diameter on the inclination

is determined by practical trials, also in part from theoretical grounds (laws of air resistance).

§ 5. PITCH OF SCREW.

1. The length of a complete thread measured on the axis.

2. **Constant pitch.**—When the pitch is the same throughout (fig. 140).

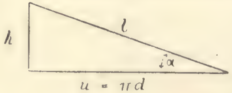


FIG. 140.

u = circumference of the screw circle,
l = developed helix,
h = pitch of screw,
α = pitch angle or angle of screw,

$$\tan \alpha = \frac{h}{\pi d} = 0{\cdot}3183 \frac{h}{d} \cdot$$

3. **Varying peripheral pitch.** — To lessen the windage (fig. 141).

Mean peripheral pitch.—The arithmetical mean of h_a and h_e.

4. **Radially varying pitch.**—All points of the generating line which lie beyond the boss have a smaller pitch than those nearer the circumference.

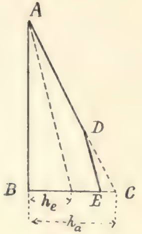


FIG. 141.

$h_a > h_e$,
h_a = outside pitch,
h_e = inside pitch,
$h_e = 0{\cdot}9$ to $0{\cdot}8 \times h_a$.

5. **Peripherally and radially varying pitch.**—Formed by a combination of the two preceding cases.

§ 6. FORMS OF SCREWS.

1. **The mathematical screw.**—Projection of blade the sector of a circle. Blades rounded and mostly of constant pitch at the boss. Disadvantage: friction and windage large, big centrifugal motion of the air. Advantage: easily made without models, and therefore cheap.

2. **The new French screw.**—Constant pitch, straight line as generating line, centre line of the screw surface an Archimedes spiral. Advantage: limitation of centrifugal motion of the air, diminution of windage.

3. **The Mangin screw.**—A two-bladed mathematical screw, in which each blade is divided in halves by a plane through a normal to the axis. One-half is set immediately behind the other on the shaft. Usually have a varying peripheral pitch. Advantage: small breadth of blade.

4. **The Griffith screw.**—Spherical boss of diameter one-third of the diameter of the propeller blades, generating line in the plane of the axis, a straight line up to the middle, then a

slightly curved line up to the circumference, breadth of blade at the boss ⅓ D, at the end ⅙ D. Advantage: works free from windage.

5. **The Hirsch screw.**—The blades are curved forward, the axis of the blade being approximately a spiral curve, instead of the usual straight line; generating line: an Archimedes spiral in the plane of projection. The projected blade surface is symmetrical with respect to the generating line, the pitch increases towards the circumference, and there are other minor peculiarities. Advantages: little windage, great velocity. Disadvantages: complicated screw; does not reverse well.

6. **The Thornycroft screw.**—The generating line in the plane of the axis is curved backwards, $h_a - h_e$ constant, blades similar to those of the Griffith screw in the plane of projection.

7. **The Penaud screw**, also known as the vane screw, only the rim consists of rigid, the blades being of loose, material.

§ 7. THE SLIP.

1. The slip is the difference between the velocity of the propeller and that of the air-ship.

2. **The true slip.** — The difference between the velocity of the air thrown behind by the screw and its entry velocity v (air-ship velocity.)

Or: the acceleration which the air entering the propeller receives in the opposite direction to that of the air-ship.

3. The apparent slip may be divided into the positive and negative slip. The apparent slip is the difference between the velocity of the propeller and the velocity of the air-ship.

4. The positive slip is the apparent slip as long as it remains a positive quantity.

u = velocity of the propeller in m. per sec.,

v = velocity of the air-ship,

$u - v$ = slip of the screw,

$$s = \frac{u-v}{u} = \text{slip of the screw expressed as a fraction of the speed of the screw,}$$

$$\rho = \frac{100\,(u-v)}{u} = \text{percentage slip.}$$

5. The negative slip is the apparent slip if $v > u$, and indicates a very small efficiency.

6. Calculation of the true slip.

Let c = velocity of the current entering the screw,

and let $x = \frac{c}{v}$; *i.e.* $c = xv$.

We must include the quantity c for the difference between the screw and air-ship velocities.

$$u - v + xv = u - v\,(1 - x),$$

or as a percentage of the velocity of the screw,

$$\rho_1 = \frac{100\,[u - v\,(1 - x)]}{u};$$

or if h = pitch,

$u = \frac{hn}{60}$ when n is the number of revolutions per minute

$\rho = \frac{100\,(hn - 60\,v)}{hn}$ per cent.,

where v is given in metres per second.

7. Freminville's experiments on slip :—The slip increases with the resistance, slightly with the rate of revolution, and with the pitch (?). Hence large screws. It increases with a diminution of the length ; the number of blades is without influence as long as their length remains constant.

8. According to Sennet the slip diminishes with an increase of the blade length.

The slip diminishes very rapidly until the length (breadth) is 30 per cent. of the pitch. In increasing the length (breadth) between 30 per cent. and 75 per cent. of the pitch, the slip diminishes more slowly, and if the length is increased beyond 75 per cent. remains practically unaltered.

Whether and how far results of observations on screws in water may be applied to air screws has yet to be determined.

§ 8. SPECIFICATION OF THE SCREW.

A certain number of parts must be specified for every screw. It is best to enter in tabular form all the specified and consequently known parts.

For every screw which is intended to be made with scientific accuracy we must have given :

1. The type of screw.
2. The form } of the generating line.
3. The position } of the generating line.
4. The form } of the sets of blades.
5. The number } of the sets of blades.
6. The vertical distances } of the sets of blades.
7. The form and diameter } of blades.
8. The position } of blades.
9. The centre of pressure } of blades.
10. The number } of blades.

11. The angle of pitch.
12. The actual pitch.
13. The longitudinal } section.
14. The cross } section.
15. The material.
16. The form of boss.
17. The total weight.
18. The number of revolutions.

In connection with these parts we must note:

to 2, if the generating line is a straight line.
,, ,, is a simple curved line.
,, ,, is a complex curved line.
to 3, ,, ,, is set at right angles to the axis.
,, ,, is inclined, and if so at what angle to the axis.
to 4, if the screw is right-handed.
,, ,, left-handed.
to 6, need only be specified for multiple screws.
to 7, either the projected or the developed surface of the blade must be shown by a drawing.
to 8, with respect to the axis.
to 9, if single- } bladed.
two- } bladed.
if multiple-bladed.
to 10, if it must have a constant } pitch and the law of its variation.
,, ,, variable peripheral
,, ,, ,, radial
,, ,, ,, peripheral and radial
to 11, expressed by $\tan\alpha = \frac{h}{\pi d}$.
to 15, on account of the surface friction } of the screw.
,, ,, elasticity } of the screw.
to 16, given by drawings. Height, diameter, strength, and shape.
to 17, The weight of the boss and screw.

If we wish to specify a screw precisely, all the above given parts must be given in detail. This is best accomplished with the aid of a table, such as that given on p. 429.

§ 9. PROPULSION.

1. All air screws set the air-ship into motion by the forward reaction of the current of air thrown out behind. This reaction is communicated by the propeller to the air-ship, and is equal and opposite to the resistance for uniform velocity of the air-ship.

2. The single particles of the current of air acted upon by the air

TABULAR FORM FOR SCIENTIFIC DATA OF SCREWS.

Type.		1	
Form	of the generating line.	2	
Position	of the generating line.	3	
Form	of the sets of blades.	4	
Number	of the sets of blades.	5	
Vertical distance	of the sets of blades.	6	
Diameter	of the blades.	7	
Position	of the blades.	8	
Longitudinal section	of the blades.	9	
Cross section	of the blades.	10	
Circle FK — surface	of the blades.	11	
Developed *Fa* — surface	of the blades.	12	
Projected *Fp* — surface	of the blades.	13	
Partial fraction of the pitch	of the blades.	14	
Number	of the blades.	15	
Position	of the blades.	16	
Centre of pressure	of the blades.	17	
Form	of the pitch.	18	
Size in *m*.	of the pitch.	19	
Greatest inclination (α).		20	
Material.		21	
Form of boss.		22	
Total weight.		23	
Rate of revolution.		24	

screw enter the propeller with a velocity of v metres per second, equal to the velocity of the air-ship, are accelerated by it, and are thrown out behind with a greater velocity V metres per second.

The increase in the velocity of the air is therefore

$$s = V - v \text{ m. per sec.}$$

3. If the current of air has a cross sectional area of F sq. m., then FV cub. m. of air enter the propeller per second.

If 1 cb. m. air weighs γ kg., and g is the acceleration of gravity, then the mass m of air thrown behind by the propeller is:

$$m = \frac{\gamma}{g} FV.$$

4. According to the law of momentum "the impulse of a force P acting for a time t is equal to the increase of momentum which the mass m acted on receives in this time," or

$$Pt = m(V - v).$$

If the time t is taken as 1 second, then the force or pressure exercised by the mass m, moving with acceleration $s = V - v$ m. per sec.^{2} in the direction of its motion, equals the reaction of the current of air moved by the air screw.

$$P = m(V - v) \text{ kg. m. per sec.}^2$$

or

$$P = \frac{\gamma}{g} FV(V - v) \text{ in kg. weight.} \quad . \quad . \quad (a)$$

As soon as the motion of the air-ship has become uniform the reaction or forward thrust P of the propeller is equal to the head resistance R.

The work done by the resistance of the ship moving forwards with a velocity of v m. per sec. is therefore:

$$Rv = m\, s\, v$$
$$= \frac{\gamma}{g} FV(V - v)v.$$

5. On the assumption that all particles of the air current enter the propeller with the velocity v of the air-ship, and are uniformly accelerated by it until the velocity is $V = v + s$, then the path traversed in unit time by the propeller in overcoming the air resistance R is $v + \frac{s}{2}$.

The propeller performs therefore an amount of work:

$$R\left(v + \frac{s}{2}\right) = Rv + R\left(\frac{V - v}{2}\right);$$

i.e. in addition to the work Rv given in the formula (a), we must take into account the work $R\,\frac{s}{2}$ necessary to bring about the acceleration of the air particles.

Since now "the work done by a force acting over a certain

distance is equal to the gain of kinetic energy of the mass m, acted upon over this distance, we get

$$R\frac{s}{2} = R\left(\frac{V-v}{2}\right) = m\frac{s^2}{2} = \frac{m}{2}(V-v)^2$$

for the kinetic energy possessed by the current of air, leaving the air screw with the velocity V.

This work or kinetic energy represents the loss of work in the propeller, and is:

$$R\frac{V-v}{2} = \frac{\gamma}{2g}FV(V-v)^2 \quad . \quad . \quad . \quad (\beta)$$

6. The work L, which must be supplied to keep the air screw in motion, is now, neglecting the friction and windage, equal to this loss of energy and the work done in overcoming the resistance of the ship, or

$$L = R\left(v+\frac{s}{2}\right) = Rv + R\left(\frac{V-v}{2}\right) = R\left(\frac{V+v}{2}\right)$$

$$= \frac{\gamma}{g}FV(V-v)v + \frac{\gamma}{2g}FV(V-v)^2$$

$$= \frac{\gamma}{2g}FV(V^2-v^2) \text{ m. kg.} \quad . \quad . \quad . \quad . \quad . \quad (\gamma)$$

7. The efficiency of the air screw is the quotient

$$\eta = \frac{R-v}{L} = \frac{\text{work in overcoming resistance of air-ship}}{\text{total work of the propeller}}$$

$$= \frac{\text{useful work}}{\text{total work}}$$

$$\eta = \frac{\frac{\gamma}{g}FV(V-v)v}{\frac{\gamma}{2g}FV(V^2-v^2)} = \frac{2v}{V-v}.$$

This is the maximum efficiency which can possibly be attained by the air-ship, and is based on the assumption that the whole of the air set into motion by the propeller is thrown out behind, and works without friction or windage, conditions which are obviously never fulfilled in practice. If $V=v$, then $\eta=1$, *i.e.* the velocity of the current thrown out of the air-screw is equal to the velocity of the air-ship, in which case, neglecting friction and windage, there is no loss of energy in the propeller. In this case the acceleration of the current of air is zero, and as there is no reaction $(\gamma)=0$.

8. From the formula (α) we may see that the reaction of air screws, under otherwise similar conditions, depends principally on the product FV. The smaller V is, the greater F must be, and since the efficiency of the propeller becomes always greater the smaller V is made, it follows that:—

"Those air-screws which move a stream of air of the greatest cross-section with the smallest velocity are theoretically the most efficient for a forward movement."

9. It is advisable to make the cross-section F of the air leaving the propeller as great as possible, so that V, its velocity, may be as small as possible.

The greater V, the smaller is η.

10. The efficiency of different air screws varies greatly. Screws have been constructed of 20, 30, 50 per cent., and even higher efficiencies.

One of the principal problems to be solved at the present day is to discover an air propeller of a really high efficiency.

§ 10. AIR SCREWS ALREADY TESTED.

The following air screws have been applied to navigable balloons :—

Name of constructor.	Date.	H.P.	Screws.						
			Number.	Diameter.	Inclination.	Number of blades.	Rate of revolution.	Pull exerted by propeller.	Weight.
			i	*m*	*m*	*i*	*n*	kg.	kg.
Giffard	1852	3	1	3·5	..	3	110	..	..
Giffard	1855	..	1	..	..	..	..	..	..
Dupuy de Lôme	1872	3	1	9·0	..	4	21–27	..	..
Haenlein	1872	3·6	1	4·6	6°	4	90–180	..	..
Tissandier	1884	1·5	1	2·9	..	2	60–120	..	..
Renard-Krebs	1884	9·0	1	6 7	..	..	..	..	..
	1885	..	..	7	..	2	40–46	..	..
Yon	1886	..	1	11	11°	2	70	..	..
Wölfert	1887	12	2	3·5	19°	3	..	..	..
Wölfert	1896	8	2	2·5	..	2	500	..	..
Schwarz	1897	16	3 or 4	2·0 or 2·75	..	2	480	..	..
Zeppelin	1900	32	4	1·25 / 1·15	19° / 33°	3 / 4	900 1100 1200	41	15 to 25
Santos Dumont I.	1899	..	1	..	..	2	..	..	..
" II.	1900	..	1	..	..	2	..	..	..
" III.	1900	..	1	..	..	2	..	..	..
" IV.	1901	16	1	..	..	2	..	..	..
" V.	1901	16	1	4	4°	2	150	..	..
" VI.	1901	16	1	2	..	..	..	..	..
Lebaudy	1903	35	2	2·8	..	2	1000 (max.)	..	..

§ 11. EXPERIMENTAL FACTS RELATING TO AIR SCREWS.

Jarolimek has given the following facts relating to air screws, based on experimental trials :—

1. The blades of a propelling screw must have extremely small pitch angle for very high rates of revolution.

2. In order to reduce the weight of the blade per unit area to a minimum, systems of many small blades must be used instead of a few large blades.

3. In order to obtain the most favourable results, the proportion between the angle and the velocity of the blades must fulfil a certain mathematical condition.

4. In order to attain a given driving force with a given minimum blade angle, the weight of the motor, including parts, must be taken as equal to double the weight of the flying apparatus.

5. If, on the contrary, only the weight of the motor or only the weight of the blades is to be a minimum, the ratios of the weights must be different.

6. The screws are made of sheet steel, aluminium offering no particular advantage as a material for the construction of such screws.

7. In order to increase the driving power of the blades per unit surface as much as possible for a constant peripheral velocity, it is an advantage to make the blades slender and long. It must not, however, be overlooked that the ratio between the length and breadth of the blade also alters the weight of the blade per unit surface, since the latter increases as the square root of the quotient of these quantities.

8. The blades should be manufactured of plane and smooth sheet steel, which can be kept very thin if the rigidity is sufficiently great, and which cuts through the air with but little friction.

9. The blades should work at inclinations of at most from 1–20°, and with peripheral velocities up to 60 or even 80 metres per second.

Wellner estimates that the efficiency of a two-bladed screw, built by him, of $d=4{\cdot}25$ m., $b=1{\cdot}24$ m., $F=3{\cdot}473$ sq. m., pitch$=1{\cdot}08$ m., $G=2{\cdot}5$ kg., driving force 40–70 kg., *i.e.* 18–20 kg. per sq. m., for which 1 H.P. lifted 15 kg., was 20 per cent. *Zeitschrift d. öst. Ing. u. Archit. Vereins*, 1894, Nos. 33, 34, 47, and 1895, Nos. 35 and 36. von Loessl experimented with screws of $d=0{\cdot}25$ m., $b=0{\cdot}1$ m., for $v=2$–3 m. per sec., and found the following efficiencies, which were published in the *Zeitschrift für Luftschiffahrt*, vol. xii., p. 151.

Two-Bladed Screw of Tin. Area of Blade Surface 0·05 sq. m.

Inclination of blades.	Plane blades.	Curved blade surfaces. Ratio of height of arc to chord. 1 : 12 Subtending at the centre an angle of :— 36°	1 : 7 60°	1 : 2 90°	Fabric blades.
30°	0·26	0·41	0·25	0·26	0·23
40°	0·33	0·45	0·38	0·30	0·39
45°	0·34	0·46	0·39	0·31	0·43
50°	0·28	0·42	0·38	0·29	0·38
60°	0·15	0·30	0·29	0·22	...

The velocities of the centre of pressure—

for a blade inclination of	30°	40°	45°
were	2·5	1·8	1·6 m. per sec.

Kress states that his screws gave an efficiency of 55 per cent. The efficiency increased with the diameter.

The Maxim screw has, as far as published data go, a breadth of about 1·5 m., a total surface of 4 sq. m., a pitch of 4·9 m., and an angle of ascent of 6°·37. At the centre of pressure the screw has a velocity of not quite 80 m. per sec. at 375 revs. per minute; 150 H.P. are lost owing to the slip.

In Zeppelin's balloon, the diameter of the screw at the centre of gravity of the surface was 0·75 m.; for $n=900$, the mean velocity was $v=35$ m. per sec., at the tip 54 m. per sec., mean angle of ascent $\alpha=18·5°$. Surface of a blade 0·129 sq. m., of the propeller 0·516 sq. m. Area of screw disc 1·039 sq. m. *Illustrierte Aëronautischen Mitteilungen*, 1902.

W. G. Walker and Patrick Y. Alexander experimented with five different air screws up to $v=27$ m. They found: (1) that the driving force varies as the square of the number of revolutions per minute; (2) that the power necessary varies as the cube of the number of revolutions per min.; (3) that the driving force with respect to the work done varies inversely as the number of revolutions per min. *Cf.* Chapter XII. *B*, § 2.

§ 12. LITERATURE.

Taylor, *Resistance of Ships and Screw Propulsion*, 1893. Literature of ship-building, such as Busley's *Schiffsmaschinen* and Wilda's *der Schiffsmaschinenbau*, 1901, pp. 304–378.

Ponton d'Amécourt, *Collection de Mémoires sur la Locomotion aérienne sans Ballons*, 1864.

Renard, "La Machine à essayer les Hélices," *Revue de l'Aéronautique*, 1888 ; *Aeronautics*, 1893.

Vogt, "The Air Propeller," *Proceedings of the International Conference on Aerial Navigation*, 1894.

"Expériences de M. Wellner," *Revue de l'Aéronautique*, 1894.

Jarolimek in the *Zeitschrift des oesterreichen Ingenieur- und Architekten-Vereins*, 1893, Nos. 30 and 31.

Hoernes in the *Zeitschrift für Luftschiffahrt*, 1897.

Kadarz, "der Luftpropeller," *ibid.*, 1896, pp. 103, 145, and 176.

Hoernes, *Lenkbare Ballons*, pp. 212–214 and 296.

William George Walker and Patrick Y. Alexander, "The Lifting Power of Air Propellers" in *Engineering*, 16th February 1900.

Hiram Maxim, "Natural and Artificial Flight," *Aeronautical Annual*, 1900.

CHAPTER XVI.

AERONAUTICAL SOCIETIES.

A.—*INTERNATIONAL SCIENTIFIC SOCIETIES.*

§ 1. THE INTERNATIONAL COMMISSION FOR SCIENTIFIC AERONAUTICS.

FOUNDED in Paris in September 1896. The members include the directors of Meteorological Institutes in all countries.

President.—Professor Hergesell of Strassburg.

Object of Commission.—To investigate the conditions holding in the atmosphere up to the highest limit attainable by kites and balloons. Simultaneous ascents are made with this object from various meteorological stations all over Europe on the first Thursday in each month (or on the following day if this be a public holiday in any of the countries participating in the ascents).

The observations are published in the *Veröffentlichungen der Internationalen Kommission für wissenschaftliche Luftschiffahrt*, edited by Professor Hergesell.

The Commission has hitherto met as under:—**1898**, 31st March to 4th April, at **Strassburg.** *Cf. Protokoll über die vom* 31 *März bis* 4 *April* 1898 *zu Strassburg i. E. abgehaltene erste Versammlung der Internationalen Aëronautischen Commission*; also *I. A. M.*, 1898, No. 3; *Meteorologische Zeitschrift*, 1898; *L'Aérophile*, 1898, p. 22; **1900**, 10th to 15th September, in **Paris.** *Cf.* "Congrès international de météorologie tenu à Paris du 10. au 16. September 1900." *Procès-verbaux sommaires*, par A. Angot, Paris, 1901; *I. A. M.*, 1900, p. 132; *L'Aérophile*, 1900, p. 111; **1902**, 20th to 25th May, in **Berlin.** *Cf. Protokoll über die zu Berlin abgehaltene dritte Versammlung der Internationalen Kommission für wissenschaftliche Luftschiffahrt*, Strassburg, 1903; *I. A. M.*, 1902, p. 138; **1904**, 29th August to 3rd September, in **St Petersburg.** *Cf.* "Quatrième conférence de la Commission Internationale par l'aérostation scien-

tifique après l'académie impériale des sciences de St Pétersbourg." *Procès-verbaux des séances et mémoires.* St Petersburg, 1905; **1906**, on the 30th September, at **Milan.**

Offices.—Meteorologischer Landesdïenst, Strassburg i. E.

§ 2. THE PERMANENT INTERNATIONAL AERONAUTICAL COMMITTEE.

(Commission Permanente Internationale d'Aéronautique.) Founded by a resolution of the International Aeronautical Congress at Paris in 1900, in order to carry out the expressed wish of the congress to advance the progress of Aeronautics by scientific advice, and to prepare for the following congress. *Offices.*—In the buildings of the *Société d'encouragement*, 44 rue de Rennes, Paris.

The transaction of business is regulated by statutes published in 1901. The congress elected 33 members, who received the right to co-opt other members and to appoint subcommittees for special subjects.

The following are the present (June 1906) members of the Committee, those elected by the Congress being indicated by an asterisk.

* Patrick Y. Alexander, Rothesay, Spencer Road, Southsea, Hants, England.

* Richard Assmann, Director of the Royal Meteorological and Aeronautical Observatory at Linderberg, near Beeskow, Germany.

* Cailletet, Member of the Academy, 75 Boulevard Saint Michel, Paris (5).

* Canovetti, Engineer, 45 Foro Bonaparte, Milan.

* Cassé, Engineer, 7 rue de l'écluse, Paris.

O. Chanute, Consulting Engineer, 413 E. Huron Street, Chicago, Ill., U.S.A.

Dion, Marquis de, President of l'Aéro-club, 46 Ave. de la grand armée, Paris.

* Drzwiecki, Engineer, Villa Damont, rue des Bauches, Paris.

Deslandres, Member of the Academy, 43 rue de Rennes, Paris.

* Emden, Doctor, Privatdocent at the Royal Technical High School in Munich, Schellingstrasse 107.

Espitallier, Lieutenant-Colonel, 22 rue de St Pétersbourg, Paris.

Forlanini, Engineer, 21 via Boccacio, Milan.

Favé, Marine Engineer, 13 rue de l'Université, Paris.

Guillaume, Bureau International des poids et mésures, Sèvres (S. et O.).
* Hergesell, Prof.-Dr., President of the Meteorological Service of Alsace-Lorraine, Silbermannstrasse 4, Strassburg.
* Hervé, Engineer, 1 rue Hautefeuille, Paris (6).
* Hinterstoisser, Capt., Komp.-Chef im K. u. K. Inf.-Rgt., No. 90 in Iaroslau, Galitzea.
* Hirschauer, Lieut.-Colonel du génie, Arras, France.
Houdaille, Commandant, 101 rue St Dominique, Paris (7).
Hoernes, Major, Ergänzungs Bezirks-Commandant, Aignerstrasse 8, Parsch bei Salzburg, Austria.
* Janssen, Director of the Astronomical Observatory at Meudon (S. and O.).
* Jukowski, Professor, Aeronautical Institute at Kutschino, Russia.
A. Kriloff, Director of the Russian Naval Experimental Station, St Petersburg.
Du Laurent de la Barre, 62 rue Blanche, Paris (9).
* Mallet, Aeronaut, 14 rue des Cloÿs, Paris.
* Millard, Captain, Commandant la compagnie d'aérostiers du génie, Antwerp.
* Moedebeck, Major, Batls. Kommandeur im Badischen Fussartillerie Regt. Nr. 14, Silbermannstrasse 14, Strassburg.
* Pesce, Technical Adviser to the Italian Legation, 73 rue de Grenelle, Paris (7).
* Paul Renard, Commandant, 1 avenue de l'Observatoire, Paris.
* Rotch, Director of the Blue Hill Observatory, Hyde Park, Mass., U.S.A.
* Rykatscheff, General, Director of the Central Physical Observatory at St Petersburg.
* Schiavone, Dr, Ferrandina Basilicate, Italy.
Conte Almérico da Schio, Director of the Meteorological Observatory at Vicenza, Italy.
Soreau, Engineer, 65 rue de la Victoire, Paris (9).
* Strohl, Colonel, 195 Boulevard St Germain, Paris (7).
* Surcouf, Aeronaut, 123 rue de Bellevue, Billancourt, (Seine).
* Teisserenc de Bort, Director of the Meteorological Observatory at Trappes, 33 rue Dumont d'Urville, Paris (8).
* Triboulet, 10 rue de la Pepinière, Paris (8).
* Trollope, Major, Aldershot, England.
* Comte de la Valette, Vice-president of l'Aéro Club, 6 place de la Madeleine, Paris (8).
Comte de la Vaulx, Vice-president of l'Aéro Club, 122 avenue des champs-Elysées, Paris (8).

* Voyer, Captain, Établissement Central du matérial de l'Aérostation militaire, Chalais-Meudon, France.

B.—*INTERNATIONAL AIR-SHIP SOCIETY.*

FÉDERATION AÉRONAUTIQUE INTERNATIONALE.

Founded on 14th October 1905, in Paris. Has laid down special rules and regulations which must be adopted by all amalgamated societies and clubs.

Officers, 1906.—Honorary President, M. L. Cailletet, Member of the Academy; President, H.S.H. Prince Roland Bonaparte; Vice-presidents, Professor Busley, M. Fernand Jacobs, Comte de la Vaulx; Secretary, M. Georges Besançon; Editor of Proceedings, M. Edouard Surcouf; Treasurer, M. Paul Tissandier.

The societies and clubs belonging to this International Federation are indicated by an asterisk (*).

C.—*NATIONAL SOCIETIES.*

I. DEUTSCHER LUFTSCHIFFER-VERBAND.*

Founded at Augsburg on the 28th December 1902, for the purpose of increasing the general interest in aeronautical matters, and more especially for—

1. Supporting a monthly aeronautical journal (*Illustrierte Aëronautische Mitteilungen*); Editor, Dr. Stolberg, Möllerstrasse 9, Strassburg i. E.
2. The publication of a year-book.
3. The superintendence of the training of aeronauts.
4. The publication of the qualifications necessary for an aeronaut as laid down by the society (*cf. I. A. M.*, 1903, p. 62).

The following German societies belong to this National Federation:—

1. Berliner Verein für Luftschiffahrt.—Founded on 31st August 1881, in Berlin. First ordinary meeting 8th September 1881. Published the *Zeitschrift für Luftschiffahrt* from 1882–1900, when the *Illustrierte Aëronautischen Mitteilungen* was adopted as the official journal of the Verein.

The Verein owns several balloons, and has arranged numerous ascents since 30th January 1891. The scientific balloon ascents of the Verein, carried out under the patronage of H.R.H. the

Kaiser, are famous. (*Cf.* Assmann-Berson, *Wissenschaftliche Luftfahrten*, Braunschweig, 1900.) The society has instituted stations for balloon ascents all over Germany, wherever the balloons could be conveniently inflated. The Verein possesses a comprehensive library of some 700 volumes. Annual subscription, 20 M. Headquarters, Dresdenerstrasse 38, Berlin. (Telephone No. 9779 IV.) Number of members (1906), 807, including 134 qualified aeronauts. Ladies are admitted as members. (*Cf. Z. f. L.*, 1887, p. 354: *Jahresbericht des deutschen Luftschiffer-Verbandes*, Strassburg, 1903; Berlin, 1904; Graudenz, 1905; Berlin, 1906.)

2. **Münchener Verein für Luftschiffahrt.**—Founded on 21st November 1889, at Munich (*cf. Z. f. L*, 1890, p. 23). Published Annual Proceedings up to 1901. Contributed to the *Zeitschrift für Luftschiffahrt* up to 1898, and subsequently to the *Illustrierte Aëronautischen Mitteilungen.* Owns balloon stores, and has arranged numerous ascents since 19th June 1889. Has a library of 70 volumes. Membership on 1st April 1906, 383, including 53 qualified aeronauts. Annual subscription, 6 M. Headquarters, Kaufingerstrasse 26, Munich.

3. **Oberrheinischer Verein für Luftschiffahrt.** — Patron, S. D. Hermann Fürst zu Hohenlohe-Langenburg, Statthalter von Elsass-Lothringen. Founded on 24th July 1896, at Strassburg. Published the *Illustrierte Mitteilungen des Oberrheinischen Vereins für Luftschiffahrt* up to 1898, when this journal was reorganised as the *Illustrierte Aëronautischen Mitteilungen.* Owns balloon stores, and has arranged numerous ascents since 1897. The library contains about 70 volumes. Membership (April 1906), 200, including 25 qualified aeronauts. Annual subscription, 7 M. Headquarters, Münsterplatz 9, Strassburg i. E.

4. **Augsburger Verein für Luftschiffahrt.**—Founded in June 1901, at Augsburg. Owns balloon stores, and has arranged ascents since 1901. Has a library of 120 volumes. Membership in April 1906, 321, including 36 aeronauts. Annual subscription, 6 M. Headquarters, Carolinenstrasse 83, Augsburg. (Telephone No. 265.)

5. **Niederrheinischer Verein für Luftschiffahrt.**—Founded on 15th December 1902, at Barmen. First ascent 8th January 1903. Owns balloon stores. Membership on 1st April 1906, 633, including 15 aeronauts. Annual subscription, 12 M. Headquarters, Königstrasse 35, Barmen. (Telephone No. 1891.)

6. **Posener Verein für Luftschiffahrt.**—Founded on 2nd December 1903, at Posen. First ascent 19th December 1903. Membership in April 1906, 83, including 9 aeronauts. Annual subscription, 20 M. Headquarters, Gartenstrasse 10 II., Posen.

7. **Ostdeutscher Verein für Luftschiffahrt.**—Founded on 11th June 1904, at Graudenz, West Prussia. First ascent 17th July 1904. Number of members, April 1906, 150, including 10 aeronauts. Annual subscription, 20 M. Owns balloon stores and a library of 145 volumes. Headquarters, Ostbank für Handel und Gewerbe, Pohlmannstrasse 9, Graudenz.

8. **Fränkischer Verein für Luftschiffahrt.**—Founded on 12th May 1905, at Würzburg. First ascent 28th February 1905. Membership, April 1906, 150, including 6 aeronauts. Annual subscription, 6 M. Library in course of formation. Headquarters, K. Hackstetter, Bergmeisterstrasse 11, Würzburg.

9. **Mittelrheinischer Verein für Luftschiffahrt.**—Founded on 11th May 1905, at Coblence. Membership, April 1906, 83, including 4 aeronauts. Annual subscription, 20 M. Headquarters, Dr Wollner, Casinostrasse 37, Coblence.

II. AUSTRIAN AND SWISS SOCIETIES.

10. **Flugtechnischer Verein in Wien.**—Founded on 18th August 1887, in Vienna, as an offshoot of the Österreichischer Ingenieur-Verein (*cf. Z. f. L.*, 1888, pp. 27, 32, 61, and 254). Contributed towards the publication of the *Zeitschrift für Luftschiffahrt* up to 1901, when it adopted as its official organ the *Illustrierte Aëronautischen Mitteilungen*. Has a library of some 100 volumes. Contributed towards the cost of W. Kress's flying machine. Annual subscription, 20 Kronen. Membership 1906, about 90. Headquarters, Eschenbachgasse 9, Vienna I.

11. **Wiener Aëro-Club.** — Patron, S. K. u. K. Hoheit Erzherzog Franz Ferdinand. Founded in August 1901, in Vienna. The club possesses its own filling grounds and balloon stores, and has organised ascents since 9th August 1901. Publishes a monthly journal, *Wiener Luftschiffer-Zeitung*. Entrance fee, 50 Kr. (for officers, 20 Kr.). Membership at beginning of 1906, 79, including 9 aeronauts. Headquarters, Annahof 3, Vienna I. (Telephone No. 393.)

12. **Schweizerischer Aëro-Club. Aéro-Club Suisse.***—Founded on 30th March 1901, at Berne. The club owns balloon materials and a small library. First ascent 11th July 1902. Membership in March 1906, 140. Headquarters, Hirschengraben 3, Berne.

III. SOCIETIES AND CLUBS OF OTHER NATIONS.

13. **The Aëronautical Society of Great Britain.**—Founded on 12th January 1866, and consequently the oldest Aëronautical Society. First general meeting on 27th June 1866. Brought

out from 1866 till 1892 yearly *Annual Reports*, and has published quarterly since 1897 *The Aëronautical Journal of Great Britain.* In 1901 the Society founded an Aëronautical Museum. Annual subscription, one guinea. Membership 1906, 120. Office and library of the Society, 53 Victoria Street, London, S.W. President, Major B. Baden-Powell, F.R.A.S. Honorary Secretary, Eric Stuart Bruce, M.A. General meetings are held at the Society of Arts, John Street, Adelphi, London.

14. **The Aëro-Club of the United Kingdom. A society for the encouragement of aërial locomotion.*** — Founded in January 1902, in London. Does not, as yet, possess balloon stores of its own, though several of its members own balloons. Annual subscription, £2, 2s. Membership, 170. Headquarters, 119 Piccadilly, London, W. Telegraphic Address, Aëroplane, London. (Telephone No. 2140 Gerrard.)

15. **The Aëro-Club of America.**—Founded in December 1905, in New York. Number of members in April 1906, 275. Annual subscription, 10 dollars. Library in course of formation. Publishes *The Aeronautical News* monthly. Editor, Carl Dienstbach, 81 Greenwich Street, New York. Headquarters, 753 Fifth Avenue, New York City. Cable address, "Aeromerica," New York.

16. **Svenska aëronautiska Sällskapet.**—Founded at Stockholm on 15th December 1900. Has procured stores especially adapted for prolonged ascents (Unge's system). Membership about 80. Annual subscription, 10 kronen. Secretary, Luÿtnant E. Fogman, Stockholm.

17. **Société Français de Navigation Aérienne.**—Founded in Paris on 12th August 1872. Has published *L'Aéronaute*, a monthly journal, since its foundation. This society is the oldest Aeronautical Society in France. It has an excellent library and museum. Annual subscription, 12 francs. Number of members, 103. Headquarters, Hôtel des ingénieurs civils de France, 19 rue Blanche, Paris.

18. **Aéronautique Club de France.***—Founded on 20th October 1897. Has branches in Paris and Lyons. Its objects are the propagation of a knowledge of aeronautical matters and the education of as many aeronauts as possible among the civil population. Membership, 350 in Paris, 150 in Lyons. Its official organ is *L'Aéronautique*, published quarterly since 1902. The club has a library and museum. The balloon ground is at Rueil (S. et O.); the stores in Palaiseau. Entrance fee for *membres associés*, 10 francs; for *membres actifs*, 5 francs; for *membres titulaires*, nil. Annual subscription, 60, 24, and 6 francs respectively, while *membres honoraires* pay a subscription of 25 francs. Ladies are admitted as members. Annual distribution of medals and prizes to balloon conductors

belonging to the society. Headquarters and library, 58 rue Jean Jacques Rousseau, Paris.

19 **Aéro-Club, Société d'encouragement à la locomotion aérienne.*** — Founded in Paris on 21st December 1898. Adopted the monthly journal *L'Aérophile* as its official organ in 1901. The club is distinguished for its great generosity in aeronautical matters. In 1900 it offered the Deutsch prize of 100,000 francs to the first aeronaut to start from the Park St Cloud, go round the Eiffel Tower, and return to the starting-point within 30 minutes. The prize was won by Santos Dumont on 19th October 1902. In 1903 numerous medals (gold, silver, and bronze) were offered in connection with various competitions and balloon sports. Annual subscription, 60 francs. Membership in April 1906, about 700, including some 60 aeronauts. The club has its own library and museum. Headquarters, 84 Faubourg Saint Honoré, Paris (8). Telegraphic address, Aéroclub, Paris. (Telephone No. 27620.)

20. **Académie Aéronautique de France.**—Founded in 1902. Possesses balloon stores and a library. Headquarters, 14 rue des Goncourt, Paris.

21. **Société des Aéronautes du Siège.**—Founded in 1902, the membership of the society being confined to persons who escaped from Paris during the siege of 1870–71 by balloon. Honorary President, J. Janssen, member of the Academy. President, A. Tissandier. Vice-president, E. Cassiers. In 1903 the society had only 31 members.

22. **Aéro-Club du Sud-Ouest.***—Founded in Bordeaux on 1st April 1905, and affiliated with the Aéro-Club de France on 5th April. Owns balloon stores. Number of members (May 1906), 175, including, 10 conductors. Entrance fee, 20 francs. Annual subscription, 36 francs. A section of the club was formed at Pau on 2nd December 1905, comprising 21 members.

23. **Aéro-Club de Belgique.***—Founded in Brussels on 15th February 1901. Number of members (February 1906), 300. Annual subscription, 20 francs. Owns balloon stores, and published a fortnightly journal, *La conquête de l'air.* Editorial offices, 18 rue des Trois Fêtes. Headquarters, 5 place Royale, Brussels. (Telephone No. 565.)

24. **Società Aeronautica Italiana.***—Patron, H.R.H. Victor Emmanuel, King of Italy. Honorary President, H.S.H. Ludwig Amadeus of Savoy, Duke of Abruzzi. Founded in Rome on 30th March 1904. The society is split up into three sections: Rome with 136 members, Turin with 29 members, and Milan with 17 members. Entrance fee, 75 lira. Annual subscription, 36 lira. Owns balloon stores and a library.

Headquarters, Corso Umberto I. 397, Rome; via Davide Bertoletti 2, Turin; via Lecco 2, Milan.

25. **El Real Aéreo-Club de España.***—Patron, H.R.H. King Alfonso XIII. Founded in Madrid on the 28th May 1905. At the beginning of 1906 had 105 members. One of the members of the club, M. Duro, succeeded in crossing the Pyrenees from Pau to Cadiz in December 1905, thus winning for the club a prize offered by the Pau section of the Aéro-Club du Sud-Ouest.

26. **Russian Aëronautical Society.**—A section of the Imperial Russian Technical Society (Section VII.), comprised since 1880 entirely of aeronauts. The membership is limited in number. Address, General A. N. Sigunoff, Panteleimonskaja 2, St Petersburg.

APPENDIX.

TABLES AND FORMULÆ.

TABLE I.

SECTION I.

ENGLISH EQUIVALENTS OF METRIC MEASURES.

1. Linear Measure.

1 centimetre . . .	=	0·3937 in.
1 metre . . .	=	39·37 ,,
1 ,, . . .	=	3·281 ft.
1 ,, . . .	=	1·094 yd.
1 kilometre . . .	=	0·6241 mile.

2. Square Measure.

1 square centimetre .	=	0·1550 sq. in.
1 square metre . .	=	10·764 sq. ft.
1 ,, . .	=	1·196 sq. yd.
1 hectare = 10,000 sq. m.	=	2·471 acres.

3. Cubic Measure.

1 cubic centimetre .	=	0·06103 cub. in.
1 cubic metre . .	=	35·32 cub. ft.
1 ,, . .	=	1·308 cub. yd.
1 litre = 1000 cub. cm. .	=	61·03 cub. in.
1 ,, . .	=	1·761 pints.

4. Mass.

1 gram	=	15·43 grains.
1 ,, ...	=	0·03527 oz. avoir.
1 ,, ...	=	0·03215 oz. troy.
1 ,, ...	=	0·002205 lb. avoir.
1 kilogram . . .	=	2·2046 lb. ,,
1 metric ton = 1000 kg .	=	0·9842 ton.

5. Velocity.

1 metre per minute	=	0·0546 ft. per sec.
1 „ second	=	3·281 ft. per sec.
1 „ „	=	2·237 miles per hr.
1 kilometre per hour	=	0·6214 „
1 „	=	0·9113 ft. per sec.

6. Acceleration.

1 metre per sec. per sec.	=	3·281 ft. per sec. per sec.

7. Density.

1 gram per cub. cm.	=	62·43 lbs. per cub. ft.

8. Force.

1 dyne (gm. cm. sec.$^{-2}$)	=	$7·233 \times 10^{-5}$ poundals.
1 „ „	=	$2·247 \times 10^{-6}$ lbs. weight.

9. Pressure.

1 dyne per sq. cm.	=	0·0672 poundals per sq. ft.
1 „	=	$4·666 \times 10^{-4}$ poundals per sq. in.
1 „	=	$1·45 \times 10^{-5}$ lbs. wt. per sq. in.

10. Work.

1 erg	=	$2·373 \times 10^{-6}$ ft. poundals.
1 „	=	$7·373 \times 10^{-8}$ ft. pounds. ($g = 32·18$ ft. per sec.^{2})
1 Joule $= 10^7$ ergs	=	0·7373 ft. pounds.
1 „	=	$3·724 \times 10^{-7}$ H.P. hrs.

11. Power.

1 watt	=	$1·341 \times 10^{-3}$ H.P.
1 force de cheval	=	0·9863 H.P.

(metric H.P. = 736 watts.)

SECTION II.

C.G.S. EQUIVALENTS OF VARIOUS UNITS.

1. Linear Measure.

German, Austrian, and Swiss.

		cm.
1 foot (Rhine) = 12 inches	=	31·385
1 inch ,, = 12 lines	=	2·615
1 line ,,	=	0·218
1 foot (Vienna) = 12 inches	=	31·611
1 inch ,, = 12 lines	=	2·634
1 line ,,	=	0·2195
1 foot (Swiss) (old)	=	28·300
1 ,, ,, (modern)	=	30·000
1 ,, (Bavaria)	=	29·186
1 ,, (Hanover)	=	29·209
1 ,, (Saxony)	=	28·319
1 ,, (Hesse)	=	28·770
1 ,, (Wurtemberg)	=	28·649
1 ,, (Baden)	=	30·000
1 rood (Prussia) = 12 feet	=	376·624
1 ,, (Bavaria) = 10 feet	=	291·859
1 Faden = 6 Prussian feet	=	188·312
1 Klafter = 6 Austrian feet	=	189·648
1 mile (Prussian) = 2000 Ruthen	=	735,250
1 mile (Austrian) = 4000 Klaften	=	758,666
1 nautical mile	=	185,230
1 geographical mile	=	742,040
1 Swiss "Stunde"	=	480,000

French.

1 foot (pied) (Paris) = 12 inches	=	32·484
1 inch (pouce) (Paris) = 12 lines	=	2·707
1 line (ligne) (Paris)	=	0·2256
1 toise = 6 feet	=	194·904
1 league (lieue) = 2000 toises	=	445,190
1 nautical league	=	556,490

English, American.

1 foot = 12 inches	=	30·4797
1 inch	=	2·5400
1 yard = 3 feet	=	91·4392
1 statute mile	=	160,935
1 nautical mile	=	185,327

Russian.

		cm.
1 Sashén = 7 English feet = 3 Arschin	=	213·36
1 Arschin = 16 Werschok	=	71·12
1 Werst = 500 Sashén	=	106,680

2. Square Measure.

		sq. cm.
1 square foot (Rhine)	=	985·02
1 ,, (English)	=	929·01
1 ,, (Paris)	=	1055·21
1 ,, (Vienna)	=	999·26
1 ,, (Swedish)	=	828
1 square inch (Rhine)	=	6·8332
1 ,, (English)	=	6·4516
1 ,, (Paris)	=	7·3278
1 ,, (Vienna)	=	6·938
1 acre = 4 roods	=	$40{,}467 \times 10^6$
1 Dessatin (Russian) = 2400 sq. Sashén	=	$1·0925 \times 10^8$

3. Cubic Measure.

		cub. cm.
1 cubic foot (Rhine)	=	30914·8
1 ,, (English)	=	28316
1 ,, (Paris)	=	34277·3
1 ,, (Vienna)	=	31588
1 Scheffel = 16 Metzen = 48 Quart	=	54961·5
1 pint	=	567·63
1 gallon	=	4541
1 gallon (wine measure)	=	3785
1 bushel	=	35238
1 Tschetwert = 8 Tschetwerik	=	$2·099 \times 10^5$
1 Tschetwerik = 8 Garnitzi	=	26238
1 Wedro = 10 Kruschka	=	12299

4. Mass.

		gm.
1 Zollpfund = 32 Lot = 128 Quentchen	=	500
1 pound (Prussian) = 32 Lot	=	467·711
1 pound avoirdupois = 7000 grains	=	453·59
1 ounce ,,	=	28·3495
1 grain ,,	=	0·064799
1 ton (English)	=	$1·01605 \times 10^6$
1 ton (metric)	=	10^6
1 imperial Troy pound	=	373·24
1 Dutch "Juvelenkarat" (jeweller's carat)	=	0·2059
1 pound (Russian) = 96 Solotnik of 96 Doli	=	409·511
1 pud (Russian) = 40 pounds	=	16380·5

5. Velocity.

	cm. sec.$^{-1}$
1 geographical mile per hour	= 206·122
1 English ,, ...	= 44·704
1 nautical ,, ...	= 51·453
1 kilometre per hour	= 27·777
1 English foot per second	= 30·4797

6. Acceleration.

	cm. sec.$^{-2}$
1 English foot per sec. per sec.	= 30·4797

7. Density.

	gm. cm.$^{-3}$
1 English pound per cubic foot	= 0·016019
1 grain per cubic inch	= 0·003954

8. Force

at a place where $g=981$ cm. sec.$^{-2}$

	dynes = gm. cm. sec.$^{-2}$
Weight of 1 gram	= 981
,, 1 kilogram	= $9{\cdot}81 \times 10^5$
,, 1 Tonne	= $9{\cdot}81 \times 10^8$
,, 1 ton	= $9{\cdot}97 \times 10^8$
,, 1 pound (avoirdupois)	= $4{\cdot}45 \times 10^5$
,, 1 ounce ,, ...	= $2{\cdot}78 \times 10^4$
,, 1 grain	= 63·57

1 poundal = 13,825 dynes, and is independent of the value of "g."

9. Pressure

at a place where $g=981$ cm. sec.$^{-2}$

	dynes per cm^2.
1 gram per square centimetre	= 981
1 kilogram ,, ...	= $9{\cdot}81 \times 10^5$
1 English pound per square foot	= 479
1 ,, ,, inch	= $6{\cdot}9 \times 10^4$
1 cm. mercury at 0° C.	= 13338
76 cm. ,, ,, ...	= $1{\cdot}0136 \times 10^6$
1 inch ,, ,, ...	= $3{\cdot}388 \times 10^4$
30 inches ,, ,, ...	= $1{\cdot}0163 \times 10^6$
76 cm. mercury at 0° C. at sea level in latitude 45° where $g=980{\cdot}65$	= $1{\cdot}0132 \times 10^6$

10. Work

at a place where $g=981$ cm. sec.$^{-2}$

		ergs.
1 gram centimetre	=	981
1 kilogram-metre	=	9.81×10^7
1 foot pound (English)	=	1.356×10^7
1 poundal	=	421,390

(the relation between the poundal and erg is independent of the value of "g.")

11. Power.

		ergs per sec.
1 horse-power (metric)	=	7.36×10^9
1 ,, (English)	=	7.46×10^9

12. Mechanical Equivalent of Heat.

		ergs.
1 gram calorie at 0° C.	=	4.22×10^7
1 ,, 15° C.	=	4.19×10^7
1 pound degree Centigrade	=	1.905×10^{10}
1 ,, Fahrenheit	=	1.058×10^{10}

Gravitational Units.

13. Pressure.

		gm. per cm^2.
1 English pound per square foot	=	0·48826
1 ,, ,, inch	=	70·31
1 inch (Paris) mercury per sq. cm.	=	36·804
28 ,, ,, ,,	=	1030·5
76 cm. mercury	=	1033·5
1 inch (English) mercury	=	34·534
30 ,, ,, ,,	=	1036·0

14. Work.

		gm. cm.
1 kilogram-metre	=	10^5
1 English foot-pound	=	13825

15. Power.

		gm. cm. per sec.
1 horse-power (Continental)	=	7.500×10^5
1 ,, (English)	=	7.604×10^5

16. Mechanical Equivalent of Heat.

		gm. cm.
1 gram-calorie	=	42400
1 pound degree Centigrade	=	$1·923 \times 10^7$
1 ,, Fahrenheit	=	$1·068 \times 10^7$

17. Electricity.

Fundamental units for electrical quantities: the centimetre, gram (mass), and second.

Practical Units.

				cm. gm. sec. units.
1. Weber:	unit of	magnetic quantity	=	10^8
2. Ohm:	,,	resistance	=	10^9
3. Volt:	,,	electromotive force	=	10^8
4. Ampère:	,,	current strength	=	10^{-1}
5. Coulomb:	,,	quantity	=	10^{-1}
6. Watt:	,,	power	=	10^7
7. Farad:	,,	capacity	=	10^{-9}

Notes.—An ohm is equal to 1·0493 Siemens units, and is about the resistance of a pure copper wire 48·5 m. long and 1 mm. in diameter, at 0° C. A volt is some 5–10 per cent. less than the electromotive force of a Daniell's cell. An ampère is the current flowing through a conductor of 1 ohm resistance, when an E.M.F. of 1 volt is maintained at its terminals. A coulomb is an ampère × second.

A watt is an ampère × volt. A German or English horse-power (H.P.) = $\frac{\text{amp.} \times \text{volt}}{746}$. A "cheval de vapeur" = $\frac{\text{amp.} \times \text{volt}}{736}$.

The legal definitions (English) of these quantities are :—

An ampère is the steady current which will deposit 0·001118 gms. of silver per second in a silver voltameter made according to specification.

A Clark cell made according to Board of Trade instructions has an E.M.F. of 1·434 volts at 15° C.

An ohm is the resistance of a column of pure mercury 106·3 cm. long, of uniform cross section, and 14·4521 gms. in mass at 0° C.

TABLE II.

Conversion Table: Millimetres into Inches.

mm.	0	1	2	3	4	5	6	7	8	9
0	0·0000	0·0394	0·0787	0·1181	0·1575	0·1968	0·2362	0·2756	0·3150	0·3543
10	0·3937	0·4331	0·4724	0·5118	0·5512	0·5906	0·6299	0·6693	0·7087	0·7480
20	0·7874	0·8268	0·8661	0·9055	0·9449	0·9843	1·0236	1·0630	1·1024	1·1417
30	1·1811	1·2205	1·2598	1·2992	1·3386	1·3780	1·4173	1·4567	1·4961	1·5354
40	1·5748	1·6142	1·6536	1·6929	1·7323	1·7717	1·8110	1·8504	1·8898	1·9291
50	1·9685	2·0079	2·0473	2·0866	2·1260	2·1654	2·2047	2·2441	2·2835	2·3228
60	2·3622	2·4016	2·4410	2·4803	2·5197	2·5591	2·5984	2·6378	2·6772	2·7166
70	2·7559	2·7953	2·8347	2·8740	2·9134	2·9528	2·9922	3·0315	3·0709	3·1103
80	3·1497	3·1890	3·2284	3·2677	3·3071	3·3465	3·3859	3·4254	3·4646	3·5040
90	3·5434	3·5827	3·6221	3·6614	3·7008	3·7402	3·7796	3·8189	3·8583	3·8977

TABLE IIA.

CONVERSION TABLE: INCHES INTO MILLIMETRES.

Inches.	0	1	2	3	4	5	6	7	8	9
0	0·0	25·4	50·8	76·2	101·6	127·0	152·4	177·8	203·2	228·6
10	254·0	279·4	304·8	330·2	355·6	381·0	406·4	431·8	457·2	482·6
20	508·0	533·4	558·8	584·2	609·6	635·0	660·4	685·8	711·2	736·6
30	762·0	787·4	812·8	838·2	863·6	889·0	914·4	939·8	965·2	990·6
40	1016·0	1041·4	1066·8	1092·2	1117·6	1143·0	1168·4	1193·8	1219·2	1244·6
50	1270·0	1295·4	1320·8	1346·2	1371·6	1397·0	1422·4	1447·8	1473·2	1498·6
60	1524·0	1549·4	1574·8	1600·2	1625·6	1651·0	1676·4	1701·8	1727·2	1752·6
70	1778·0	1803·4	1828·8	1854·2	1879·6	1905·0	1930·4	1955·8	1981·2	2006·6
80	2032·0	2057·4	2082·8	2108·2	2133·6	2159·0	2184·4	2209·8	2235·2	2260·6
90	2286·0	2311·4	2336·8	2362·2	2387·6	2413·0	2438·4	2463·8	2489·2	2514·6

TABLE III.

Conversion Table: Metres into Feet.

Metres.	0	1	2	3	4	5	6	7	8	9
0	...	3·281	6·562	9·843	13·124	16·404	19·685	22·966	26·247	29·528
10	32·809	36·090	39·371	42·652	45·933	49·213	52·494	55·775	59·056	62·337
20	65·618	68·90	72·18	75·46	78·74	82·01	85·29	88·57	91·85	95·14
30	98·427	101·71	104·99	108·27	111·55	114·82	118·10	121·38	124·66	127·95
40	131·236	134·51	137·79	141·08	144·36	147·63	150·91	154·19	157·47	160·76
50	164·045	167·32	170·60	173·89	177·16	180·45	183·73	187·01	190·29	193·57
60	196·854	200·13	203·41	206·69	209·97	213·26	216·54	219·82	223·10	226·38
70	229·663	232·94	236·22	239·50	242·78	246·07	249·35	252·63	255·91	259·19
80	262·472	265·75	269·03	272·31	275·59	278·87	282·15	285·44	288·72	292·00
90	295·281	298·56	301·84	305·12	308·40	311·68	314·96	318·25	321·53	324·81

TABLE IIIA.

CONVERSION TABLE: FEET INTO METRES.

Feet.	0	1	2	3	4	5	6	7	8	9
0	0·0000	0·3048	0·6096	0·9144	1·2192	1·5240	1·8288	2·1336	2·4384	2·7431
10	3·0479	3·3527	3·6575	3·9623	4·2671	4·5719	4·8767	5·1815	5·4863	5·7911
20	6·0959	6·4007	6·7055	7·0103	7·3151	7·6199	7·9247	8·2294	8·5342	8·8390
30	9·1438	9·4486	9·7534	10·058	10·363	10·668	10·973	11·277	11·582	11·887
40	12·192	12·497	12·801	13·106	13·411	13·716	14·021	14·325	14·630	14·935
50	15·240	15·544	15·849	16·154	16·459	16·764	17·069	17·373	17·678	17·983
60	18·288	18·892	18·897	19·202	19·507	19·812	20·116	20·421	20·726	21·031
70	21·336	21·640	21·945	22·250	22·555	22·860	23·164	23·469	23·774	24·079
80	24·384	24·688	24·993	25·289	25·603	25·907	26·212	26·517	26·822	27·127
90	27·432	27·736	28·041	28·246	28·651	28·955	29·260	29·565	29·870	30·175

TABLE IV.

Conversion Table: Pounds per Square Inch into Kilograms per Square Centimetre.

1 pound per square inch = 0·0703094 kg. per sq. cm.

Pounds per sq. inch.	0	1	2	3	4	5	6	7	8	9
0	0·0000	0·07031	0·14062	0·21093	0·28124	0·35155	0·42186	0·49217	0·56248	0·63279
10	0·70310	0·77340	0·84371	0·96402	0·98433	1·0546	1·1250	1·1953	1·2656	1·3359
20	1·4062	1·4765	1·5468	1·6171	1·6874	1·7577	1·8280	1·8984	1·9687	2·0390
30	2·1093	2·1796	2·2499	2·3202	2·3905	2·4608	2·5311	2·6015	2·6718	2·7421
40	2·8124	2·8827	2·9530	3·0233	3·0936	3·1639	3·2342	3·3045	3·3749	3·4452
50	3·5155	3·5858	3·6561	3·7264	3·7967	3·8670	3·9373	4·0076	4·0780	4·1483
60	4·2186	4·2889	4·6592	4·4295	4·4998	4·5701	4·6404	4·7107	4·7810	4·8514
70	4·9217	4·9920	5·0623	5·1326	5·2029	5·2732	5·3435	5·4138	5·4841	5·5545
80	5·6248	5·6951	5·7654	5·8357	5·9060	5·9763	6·0466	6·1169	6·1872	6·2575
90	6·3279	6·3982	6·4685	6·5388	6·6091	6·6794	6·7497	6·8200	6·8903	6·9606
100	7·0310	7·1013	7·1716	7·2419	7·3122	7·3825	7·4528	7·5231	7·5934	7·6637

TABLE V.

Specific Gravities.

1. *Solids* (water at 4° C = 1).

Alum	1·7
Aluminium, cast	2·57
,, rolled	2·68
,, drawn	2·70
Aluminium bronze—	
with 20% aluminium	6 42
,, 15 ,,	7·05
,, 10 ,,	7·65
,, 7·5 ,,	7·87
,, 5 ,,	8·15
Anthracite	1·3 –1·8
Antimony	6·66–6·86
Argentalium (Al + Sb)	2·8
Asbestos	2·05–2·80
Bismuth	9·83
Brass, cast	8·40–8·71
,, sheet	8·52–8·62
,, drawn	8·34–8·73
Calcium	1·58
Caoutchouc	0·93
Charcoal—	
from pine	0·28–0·44
from oak	0·57
Clay	1 80–2·63
Coke	1·0 –1·7
Coal	1·2 –1·5
Common salt	2·3 –2·4
Copper, cast	8·59–8·90
,, wrought	8·88–9·00
,, drawn	8·78–9·00
Earth, clay	2·1
,, dry	1·9
,, damp	1·4
Gold, native	18·60–19·10
,, cast	19·25–19·34
Ice (at 0° C.)	0·918
Iron, cast	7·00–7·50
,, wrought	7·80–7·90
,, drawn	7·60–7·75
Lead, cast	11·34
Lignite (brown coal)	1·22–1·29
Lime, burnt	2·30–3·18
Loam	1·52–2·85
Magnalium	2·4 –2·57
Magnesium	1·74
Mercury	13·60
Nickel	8·57–8·93
,, aluminium	2·9
Platinum, hammered	22·2
,, drawn	19·27
Potassium	0·87
Rubber, vulcanised	1·25–1·75
Sand, fine and dry	1·40–1·64
,, fine and moist	1·90–1·95
,, coarse	1·37–1·49
Silver, cast	10·40–10·47
,, hammered	10·51–10·61
Sodium	0·98
Steel, Bessemer	7·26–7·80
,, refined	7·50–7·81
,, cast	7·83–7·92
Tin	7·29–7·47
Victoria aluminium	
(Al + Cu + Sn)	2·8 –3·0
Wax	0·97
Wolframinium	3
Zinc, cast	7·04–7·22
,, wrought	7·19–7·28

Woods—	
Acacia	0·71–0·87
Alder	0·50–0·68
Apple	0·67–0·79
Ash	0·65–0·85
Beech	0·70–0·85
Birch	0·60–0·80
Box	0·91–1·03
Cedar	0·49–0·57
Cherry	0·70–0·90
Cork	0·22–0·26
Deal	0·56–0·89
Ebony	1·11–1·33

TABLE V.—*continued.*

Woods—		Woods—	
Elm	0·54–0·60	Lime	0·56–0·60
Fir or pine—		Mahogany	0·56
Larch	0·47–0·57	Maple	0·65–0·69
Pitch	0·83–0·85	Oak	0·62–0·95
Red	0·48–0·70	Poplar	0·38–0·47
Spruce	0·48–0·70	Satinwood	0·95
Yellow	0·37–0·60	Sycamore	0·40–0·60
Hazel	0·60–0·80	Teak	0·66–0·96
Laburnum	0·92	Walnut	0·64–0·70
Lignum vitæ (pock-wood)	1·20–1·30	Willow	0·40–0·60

2. *Liquids* (water at 4° = 1).

Alcohol at 20° C.	0·716	Mercury	13·60
Benzene	0·90	Nitric acid (conc.)	1·50
Ether abs. at 20° C.	0·792	Olive oil	0·92
Hydrochloric acid (conc.)	1·20	Petrol	about 0·80
Glycerine	1·26	Sea-water	1·025
Linseed oil	0·94	Sulphuric acid (conc.)	1·85

3. *Gases* (at 0° C. atmospheric air = 1).

1 cb. m. weighs in gms. 1·3 times the specific gravity.

Ammonia	0·596	Hydrogen	0·0696
Carbonic acid	1·529	Marsh gas	0·56
Carbon monoxide	0·967	Oxygen	1·106
Common gas (from coal)	0·48–0·51	Nitrogen	0·972
		Steam (at 100°)	0·47

Density of air as compared with that of water = 0·001293 (roughly 0·0013).

TABLE VI.

Atomic Weights of Elements.

Element.	Symbol.	Atomic Weight. H = 1.	Element.	Symbol.	Atomic Weight. H = 1.
Aluminium	Al	27	Neodidymium	Ne	142·5
Antimony	Sb	120	Neon	No	19·9
Argon	A	39·6	Nickel	Ni	58·8
Arsenic	As	75	Niobium	Nb	94
Barium	Ba	137	Nitrogen	N	14
Beryllium	Be	9 4	Osmium	Os	191
Bismuth	Bi	207	Oxygen	O	16
Boron	B	11	Palladium	Pd	106·5
Bromine	Br	80	Phosphorus	P	31
Cadmium	Cd	112	Platinum	Pt	197
Caesium	Cs	133	Potassium	K	39
Calcium	Ca	40	Praseodidymium	Pr	139·4
Carbon	C	12	Rhodium	Rh	104
Cerium	Ce	138	Rubidium	Rb	85
Chlorine	Cl	35·5	Ruthenium	Ru	101
Chromium	Cr	52·5	Samarium	Sm	149
Cobalt	Co	59	Scandium	Sc	43·8
Copper	Cu	63	Selenium	Se	79
Erbium	Er	169	Silicon	Si	28
Fluorine	F	19	Silver	Ag	108
Gadolinium	Gd	155	Sodium	Na	23
Gallium	Ga	69	Strontium	Sr	87·5
Germanium	Ge	71·5	Sulphur	S	32
Gold	Au	196·7	Tantalum	Ta	182
Helium	He	4	Tellurium	Te	127
Hydrogen	H	1	Thallium	Tl	204
Indium	In	113·4	Thorium	Th	231·5
Iodine	I	127	Thulium	Tu	170
Iridium	Ir	193	Tin	Sn	118
Iron	Fe	56	Titanium	Ti	48
Krypton	Kr	81·2	Tungsten	W	184
Lanthanum	La	139	Uranium	U	210
Lead	Pb	207	Vanadium	V	51·2
Lithium	Li	7	Xenon	X	127
Magnesium	Mg	24	Ytterbium	Yb	172
Manganese	Mn	55	Yttrium	Y	89
Mercury	Hg	200	Zinc	Zn	65
Molybdenum	Mo	96	Zirconium	Zr	90

TABLE VII.

VARIOUS GAS CONSTANTS.

	Molecular Weight.	Specific gravity.	ρ_0 kg. per cub. m.	v_0 cub. m. per kg.	R *m.*	H_0 *m.*	*a* density per mm. Hg. pressure.	c_p calories per kg.	c_v calories per kg.	*k*	u_0 *m.* per sec.
Air,	—	1	1·2927	0·7733	29·27	7991	0·001701	0·2375	0·1690	1·403	332·5
Hydrogen,	2	0·0692	0·08954	11·169	423·0	115310	0·0001178	3·409	2·411	1·40	1270
Oxygen,	32	1·1056	1·4293	0·6692	26·48	7229	0·001880	0·2175	0·1551	1·40	317
Nitrogen,	28	0·9713	1·2557	0·7963	30·13	8225	0·001653	0·2438	0·1727	1·41	337
Carbonic Acid,	44	1·5201	1·977	0·5056	19·14	5225	0·002601	0·2169	0·172	1·30	260
Marsh Gas,	18	0·6219	0·8040	1·244	47·07	12850	0·00106	0·4805	0·361	1·33	400
		0·4	0·517	1·933	73·17	19975	0·000681				
Coal Gas,	—	0·435*	0·562	1·789	69·39	18397	0·000740	0·57	0·41	1·4	500
		0·5	0·646	1·547	58·54	15982	0·000851				

* Average value in Munich, calculated from that of the constituents.

TABLE VIII.

TENSION (E) IN MILLIMETRES OF MERCURY, AND DENSITY (F) IN KILOGRAMS PER CUBIC METRE OF SATURATED WATER VAPOUR AT DIFFERENT TEMPERATURES (t° C.).

t ° C.	E mm.	F kg. per cbm.	t ° C.	E mm.	F kg. per cbm.
−30	0·38	0·00045	6	6·97	0·00722
−29	0·42	50	7	7·47	770
−28	0·46	54	8	7·99	822
−27	0·50	59	9	8·55	876
−26	0·55	65	10	9·14	933
−25	0·61	71	11	9·77	993
−24	0·66	77	12	10·43	0·01057
−23	0·73	84	13	11·14	1125
−22	0·79	91	14	11·88	1196
−21	0·87	99	15	12·67	1271
−20	0·94	0·00100	16	13·51	1350
−19	1·03	117	17	14·40	1434
−18	1·12	127	18	15·33	1522
−17	1·22	138	19	16·32	1614
−16	1·32	149	20	17·36	1712
−15	1·44	161	21	18·47	1814
−14	1·56	174	22	19·63	1922
−13	1·69	188	23	20·86	2035
−12	1·84	203	24	22·15	2154
−11	1·99	219	25	23·52	2280
−10	2·15	236	26	24·96	2411
− 9	2·33	255	27	26·47	2549
− 8	2·51	274	28	28·07	2693
− 7	2·72	295	29	29·74	2845
− 6	2·93	317	30	31·51	3004
− 5	3·16	341	31	33·37	3170
− 4	3·41	366	32	35·32	3345
− 3	3·67	393	33	37·37	3527
− 2	3·95	421	34	39·52	3718
− 1	4·25	451	35	41·78	3918
0	4·57	484	36	44·16	4127
+ 1	4·91	518	37	46·65	4346
+ 2	5·27	554	38	49·26	4575
3	5·66	592	39	52·00	4813
4	6·07	633	40	54·87	5062
5	6·51	676			

Formulæ (*cf.* Chap. I.) :—

(1a) $$\frac{p}{\rho(273+t)} = \frac{p_o}{\rho_o 273} = \mathrm{R}$$

(1b) $$\frac{pv}{273+t} = \frac{p_o v_o}{273} = \mathrm{R}$$

(3) $$\rho = \frac{p}{\mathrm{H}_o(1+at)} \quad \left(\frac{\text{kg.}}{\text{cb. m.}}\right)$$

$$\frac{b}{\rho(273+t)} = \frac{760}{\rho_o \, . \, 273}$$

(4) $$\rho = a \, . \, b \, . \, \frac{1}{1+at}$$

(12) $$\mathrm{C}_p - \mathrm{C}_v = \frac{\mathrm{R}}{423 \cdot 5}$$

(19) $$\Delta t = -\frac{1}{423 \cdot 5 \, \mathrm{C}_p s} \Delta h.$$

Constants relating to Air expressed in Absolute Units.

Normal pressure $p_o = 1 \cdot 0136 \times 10^6 \ \frac{\text{dynes}}{\text{sq. cm.}}$ [gm. cm.$^{-1}$ sec.$^{-2}$].
Normal density ρ_o at p_o and $t_o{}^\circ = 0 \cdot 0012927$ [gm. cm.$^{-3}$].
Normal specific volume at p_o and $t_o{}^\circ = 773 \cdot 3$ [cm.^{3} gm.$^{-1}$].

$$\mathrm{C}_p = 0 \cdot 2375 \ \frac{\text{gm.-calories}}{\text{gm.}} = 99 \cdot 5 \times 10^5 \ \frac{\text{ergs.}}{\text{gm.}} \ [\text{cm.}^2 \ \text{sec.}^{-2}].$$

$$\mathrm{C}_v = 0 \cdot 1690 \ \frac{\text{gm.-calories}}{\text{gm.}} = 70 \cdot 8 \times 10^5 \ \frac{\text{ergs.}}{\text{gm.}} \ [\text{cm.}^2 \ \text{sec.}^{-2}].$$

1 gram-calorie $= 41 \cdot 9 \times 10^6$ ergs. [gm. cm.^{2} sec.$^{-2}$].

Coefficient of conductivity for heat at 0° C. $k = 0 \cdot 000058 \ \frac{\text{gm.-cal.}}{\text{cm. sec.}}$

$$k_t = k_o(1 + 0 \cdot 002t).$$

Dynamical coefficient of viscosity at 15° C. $\eta = 0 \cdot 00019$ [gm. cm.$^{-1}$ sec.$^{-1}$].

$$\eta_t = \eta_o(1 + 0 \cdot 0025t).$$

Kinematical coefficient of viscosity at 15° C.

$$\frac{\eta}{\rho} = 0 \cdot 14 \ [\text{cm.}^2 \ \text{sec.}^{-1}].$$

Critical temperature of air $= -140°$ C.
Critical pressure $= 39$ atmospheres.
Critical temperature of oxygen $= -118°$ C.
Critical pressure of oxygen $= 50$ atmospheres.
Boiling point of oxygen at atmospheric pressure $= -181°$ C., its density being at that temperature 1·1.
Critical temperature of nitrogen $= -146°$ C.
Critical pressure of nitrogen $= 34$ atmospheres.
Boiling point of nitrogen under atmospheric pressure $= -193°$ C., its density being at that temperature 0·9.
Freezing point of nitrogen $-214°$ C.
1 litre of dry air in latitude λ, at a height of h metres above sea level, at a barometric pressure of b mm. mercury (reduced to normal conditions), and at a temperature $t°$ C., weighs

$$1{\cdot}2927 \times \frac{1}{1+\alpha t} \times \frac{b}{760} \times (1 - 0{\cdot}002591\ \lambda) \times (1 - 0{\cdot}00000000314\ h) \text{ gm.}$$

If dry air is reduced in pressure by an amount Δp without performing external work, its temperature decreases $\left(\frac{\Delta p}{4}\right)$°C., owing to the performance of internal work.

Coefficient of refraction of dry air (against a vacuum).

Fraunhofer's Line.	n_o.	Fraunhofer's Line.	n_o.
A	1·0002905	L	1·0002987
B	2911	M	2993
C	2914	N	3003
D	2922	O	3015
E	2933	P	3023
F	2943	Q	3031
G	2962	R	3043
H	2978	S	3053
K	2980	T	3064
		U	3075

For sodium light $n_t^p = 1{\cdot}0003015 + 0{\cdot}0000003830\ (b - 760) - 0{\cdot}0000010683 t$.

If pressure of water vapour is e mm., then for all colours

$$n_e = n - 0{\cdot}000041 \frac{e}{760}$$

TABLE IX.

FLOW OF GAS IN CUBIC METRES PER HOUR UNDER A PRESSURE OF 15 MM. (sp. gr. of gas 0·4).

Length of Pipe in Metres.	Diameter of pipe in millimetres $d=$																		
	40	50	75	100	125	150	175	200	225	250	275	300	350	400	450	500	600	800	1000
25	28	49	134	276	482	761	1119	1562	2096	2588	3462	4304	6327	8835	11860	15399	24346	49978	87309
50	20	35	95	195	341	538	791	1104	1432	1830	2448	3043	4474	6247	8386	10888	17216	35340	61707
75	16	28	78	159	278	439	646	902	1210	1495	1999	2485	3653	5101	6847	8890	14056	28855	50408
100	14	24	67	138	241	380	559	781	1048	1294	1731	2152	3164	4418	5930	7699	12173	24989	43654
125	12	22	60	123	216	340	500	698	937	1158	1548	1925	2830	3951	5304	6886	10888	22351	39046
150	11	20	55	113	197	311	457	638	856	1057	1414	1757	2583	3607	4842	6286	9939	24404	35644
175	11	19	52	106	185	292	429	599	804	993	1328	1650	2426	3388	4548	5905	9336	19166	33481
200	10	17	48	98	170	269	395	552	741	915	1224	1522	2237	3124	4193	5444	8608	17670	30868
225	9	16	45	92	161	254	373	521	699	863	1154	1435	2109	2945	3953	5133	8115	16659	29103
250	9	15	44	87	153	241	354	494	663	819	1095	1361	2001	2794	3750	4869	7699	15805	27609
275	8	15	41	83	145	229	337	471	632	780	1044	1298	1908	2664	3576	4643	7341	15069	26325
300	8	14	39	80	139	220	323	451	605	747	1000	1242	1827	2550	3432	4445	7028	14428	25204
350	7	13	36	74	129	203	299	417	560	692	925	1150	1691	2361	3170	4115	6507	13357	23388
400	7	12	34	69	121	190	280	390	524	647	866	1076	1582	2209	2965	3850	6087	12495	21827
450	7	12	32	65	114	179	264	368	494	610	816	1014	1495	2082	2795	3629	5739	11780	20579
500	6	11	30	62	108	170	250	349	469	579	774	962	1415	1976	2652	3443	5444	11176	19523
600	6	10	27	56	98	155	228	319	428	528	707	876	1292	1803	2421	3143	4970	10202	17822
700	5	9	25	52	91	144	211	295	396	489	654	813	1196	1670	2241	2910	4601	9445	16500
800	5	9	24	49	85	134	198	276	371	458	612	761	1119	1562	2097	2722	4304	8835	15434
900	5	8	22	46	80	127	186	260	349	431	577	717	1021	1473	1977	2566	4058	8330	14551
1000	4	8	21	44	76	120	177	247	331	409	547	681	1000	1397	1875	2435	3850	7902	13805
1250	4	7	19	39	68	108	158	221	296	366	490	609	895	1249	1677	2178	3443	7068	12347
1500	4	6	17	36	62	98	144	202	271	334	447	556	817	1141	1531	1988	3143	6452	11272
1750	3	6	16	33	58	91	134	187	251	309	414	514	756	1056	1418	1840	2910	5974	10411
2000	3	5	15	31	54	85	125	175	234	289	387	481	707	988	1326	1722	2722	5588	9761
2250	3	5	14	29	51	80	118	165	221	273	365	454	667	931	1250	1623	2566	5268	9203
2500	3	5	13	27	48	76	112	156	210	259	346	430	633	884	1186	1540	2434	4998	8731
2750	3	5	13	26	46	73	107	149	200	247	330	410	603	842	1128	1468	2321	4765	8325
3000	3	4	12	25	44	69	102	143	191	236	316	393	578	807	1083	1406	2223	4562	7970

Formulæ: (1) $Q=0{\cdot}0022543\,d^2\sqrt{\frac{hd}{sl}}$. (2) $d=11{\cdot}449\sqrt[5]{\frac{Q^2sl}{h}}$.

TABLE X.

Square Roots of Numbers from 0·350 to 0·700, these being the usual limits for the specific gravity of gases used in ballooning.

Sp. gr.	Square root.	Sp. gr.	Square root.	Sp. gr.	Square root.	Sp. gr.	Square root.	Sp. gr.	Square root.
0·350	0·5916	0·425	0·6519	0·495	0·7035	0·565	0·7517	0·635	0·7969
0·355	0·5958	0·430	0·6557	0·500	0·7071	0·570	0·7549	0·640	0·8000
0·360	0·6000	0·435	0·6595	0·505	0·7106	0·575	0·7583	0·645	0·8031
0·365	0·6041	0·440	0·6633	0·510	0·7141	0·580	0·7616	0·650	0·8062
0·370	0·6083	0·445	0·6671	0·515	0·7176	0·585	0·7648	0·655	0·8093
0·375	0·6124	0·450	0·6708	0·520	0·7212	0·590	0·7681	0·660	0·8124
0·380	0·6164	0·455	0·6745	0·525	0·7246	0·595	0·7731	0·665	0·8155
0·385	0·6205	0·460	0·6782	0·530	0·7280	0·600	0·7746	0·670	0·8185
0·390	0·6245	0·465	0·6819	0·535	0·7314	0·605	0·7778	0·675	0·8216
0·395	0·6285	0·470	0·6856	0·540	0·7348	0·610	0·7810	0·680	0·8246
0·400	0·6325	0·475	0·6892	0·545	0·7382	0·615	0·7842	0·685	0·8276
0·405	0·6364	0·480	0·6928	0·550	0·7416	0·620	0·7874	0·690	0·8306
0·410	0·6403	0·485	0·6964	0·555	0·7449	0·625	0·7905	0·695	0·8337
0·415	0·6442	0·490	0·7000	0·560	0·7483	0·630	0·7937	0·700	0·8367
0·420	0·6481								

TABLE XI.

Square Roots of Numbers from 1 to 100.

1	1·0000	21	4·5826	41	6·4031	61	7·8102	81	9·0000
2	1·4442	22	4·6904	42	6·4807	62	7·8740	82	9·0554
3	1·7321	23	4·7958	43	6·5574	63	7·9373	83	9·1104
4	2·0000	24	4·8990	44	6·6332	64	8·0000	84	9·1652
5	2·2361	25	5·0000	45	6·7082	65	8·0623	85	9·2195
6	2·4495	26	5·0990	46	6·7823	66	8·1240	86	9·2736
7	2·6458	27	5·1962	47	6·8557	67	8·1854	87	9·3274
8	2·8284	28	5·2915	48	6·9282	68	8·2462	88	9·3808
9	3·0000	29	5·3852	49	7·0000	69	8·3066	89	9·4340
10	3·1623	30	5·4772	50	7·0711	70	8·3666	90	9·4868
11	3·3166	31	5·5678	51	7·1414	71	8·4261	91	9·5394
12	3·4641	32	5·6569	52	7·2111	72	8·4853	92	9·5917
13	3·6056	33	5·7446	53	7·2801	73	8·5440	93	9·6437
14	3·7417	34	5·8310	54	7·3485	74	8·6023	94	9·6954
15	3·8730	35	5·9161	55	7·4162	75	8·6603	95	9·7468
16	4·0000	36	6·0000	56	7·4833	76	8·7178	96	9·7980
17	4·1231	37	6·0828	57	7·5498	77	8·7750	97	9·8489
18	4·2426	38	6·1644	58	7·6158	78	8·8318	98	9·8995
19	4·3589	39	6·2450	59	7·6811	79	8·8882	99	9·9499
20	4·4721	40	6·3246	60	7·7460	80	8·9443	100	10·0000

TABLE XII.

CONVERSION TABLE: PRESSURES MEASURED IN MM. WATER (h) INTO MM. MERCURY (b).

h	b	h	b	h	b	h	b	h	b	h	b	h	b	h	b
1	0·07	15	1·12	29	2·14	43	3·17	57	4·21	71	5·24	84	6·20	97	7·16
2	0·15	16	1·18	30	2·21	44	3·25	58	4·28	72	5·31	85	6·27	98	7·28
3	0·22	17	1·26	31	2·29	45	3·32	59	4·35	73	5·39	86	6·35	99	7·31
4	0·30	18	1·33	32	2·36	46	3·39	60	4·43	74	5·46	87	6·42	100	7·38
5	0·37	19	1·40	33	2·44	47	3·47	61	4·50	75	5·54	88	6·49	200	14·76
6	0·44	20	1·48	34	2·51	48	3·54	62	4·58	76	5·61	89	6·57	300	22·14
7	0·52	21	1·55	35	2·58	49	3·62	63	4·65	77	5·68	90	6·64	400	29·52
8	0·59	22	1·62	36	2·66	50	3·69	64	4·72	78	5·76	91	6·72	500	36·90
9	0·66	23	1·70	37	2·73	51	3·76	65	4·80	79	5·83	92	6·79	600	41·28
10	0·74	24	1·77	38	2·80	52	3·84	66	4·87	80	5·90	93	6·86	700	51·66
11	0·81	25	1·84	39	2·88	53	3·91	67	4·94	81	5·98	94	6·94	800	59·04
12	0·89	26	1·92	40	2·95	54	3·99	68	5·02	82	6·05	95	7·01	900	66·42
13	0·96	27	1·98	41	3·03	55	4·06	69	5 09	83	6·13	96	7·08	1000	73·80
14	1·03	28	2·07	42	3·10	56	4·13	70	5·17						

FORMULÆ (*cf.* CHAP. II.)

(1) $$\frac{pv}{273+t}=\frac{p_0v_0}{273}=29 \cdot 27.$$

(2) $$h=18{,}400 \log \frac{b_0}{b}.$$

(3) $$h=18{,}400 \log \frac{b_0}{b} \cdot (1+0 \cdot 0037t)\left(1+\frac{0 \cdot 377}{2}\left[\frac{e_0}{b_0}+\frac{e}{b}\right]\right).$$
$$\times(1+0 \cdot 0026 \cos 2\phi)\left(1+2\frac{\mathrm{H}}{r}\right).$$

(4) $$\mathrm{C}^o=\tfrac{5}{4}\,\mathrm{R}^o=\tfrac{5}{9}\,(\mathrm{F}^o-32).$$

(5) $$f=1 \cdot 06\,\frac{e}{1+0 \cdot 00367t}.$$

(6) $$\text{Specific humidity}=0 \cdot 623 \cdot \frac{e}{b-0 \cdot 377e}.$$

(7) $e=e'-\dfrac{0 \cdot 48(t-t')b}{610-t'}$ (ordinary psychrometer or wet and dry bulb thermometers).

(8) $e=e'-0 \cdot 5(t-t')\dfrac{b}{755}$ (ventilated psychrometer or ventilated wet and dry bulb thermometers).

(9) $e_h=e_0 \cdot 10^{-\frac{h}{6 \cdot 3}}.$

TABLE XIII.

Barometric Height Table (Height in metres).

Pressure mm.	Mean temp. of the column of air in ° C. 20°		10°		0°		−10°		−20°		Alteration for 1° C.
770	−90	11·3	−87	10·9	−84	10·5	−81	10·1	−78	9·7	0·3
760	23	11·4	22	11·0	21	10·6	20	10·3	19	9·9	0·1
750	137	11·5	132	11·1	127	10·8	123	10·4	118	10·1	0·5
740	252	11·7	243	11·3	235	10·9	227	10·5	219	10·2	0·9
730	369	11·9	356	11·5	344	11·1	332	10·7	320	10·3	1·3
720	488	12·0	471	11·6	455	11·2	439	10·8	423	10·4	1·6
710	608	12·2	587	11·8	567	11·3	547	10·9	527	10·5	2·0
700	730	12·4	705	12·0	680	11·6	656	11·2	632	10·6	2·4
690	854	12·6	825	12·1	796	11·7	767	11·3	738	10·9	2·9
680	980	12·7	946	12·4	913	11·9	880	11·4	847	11·0	3·3
670	1107	13·0	1070	12·5	1032	12·0	994	11·5	956	11·1	3·8
660	1237	13·1	1195	12·7	1152	12·3	1109	11·9	1067	11·4	4·2
650	1368	13·4	1322	12·8	1275	12·4	1228	12·0	1181	11·6	4·7
640	1502	13·5	1450	13·1	1399	12·6	1348	12·1	1297	11·6	5·1
630	1637	13·8	1581	13·3	1525	12·9	1469	12·4	1413	11·9	5·6
620	1775	14·0	1714	13·6	1654	13·0	1593	12·5	1532	12·1	6·1
610	1915	14·2	1850	13·7	1784	13·3	1718	12·9	1653	12·4	6·6
600	2057	14·5	1987	14·0	1917	13·5	1847	13·0	1777	12·5	7·0
590	2202	14·7	2127	14·2	2052	13·7	1977	13·2	1902	12·7	7·5
580	2349	15·0	2269	14·5	2189	13·9	2109	13·4	2029	12·9	8·0
570	2499	15·2	2414	14·7	2328	14·2	2243	13·7	2158	13·2	8·5
560	2651	15·6	2561	15·0	2470	14·5	2380	13·9	2290	13·3	9·0
550	2807	15·8	2711	15·2	2615	14·7	2519	14·2	2423	13·7	9·6
540	2965	16·1	2863	15·6	2762	15·0	2661	14·4	2560	13·8	10·1
530	3126	16·4	3019	15·8	2912	15·3	2805	14·8	2698	14·3	10·7
520	3290	16·7	3177	16·2	3065	15·6	2953	15·0	2841	14·4	11·2
510	3457	17·1	3339	16·5	3221	15·9	3103	15·3	2985	14·7	11·8
500	3628		3504	16·8	3380	16·2	3256	15·6	3132	15·0	12·4
490			3672	17·1	3542	16·6	3412	16·0	3282	15·4	13·0
480			3843	17·6	3708	16·8	3572	16·2	3436	15·6	13·6
470			4019	17·9	3876	17·3	3734	16·7	3592	16·1	14·2
460			4198	18·2	4049	17·7	3901	17·0	3753	16·3	14·8
450			4380	18·7	4226	18·0	4071	17·4	3916	16·7	15·5
440			4567	19·2	4406	18·5	4245	17·7	4083	17·0	16·1
430			4759		4591		4422		4253		16·9

TABLE XIII.—*continued.*

Pressure mm.	Mean temp. of the column of air in ° C.										Alteration for 1° C.
	20°		10°		0°		−10°		−20°		
420			4955	19·6	4780	18·9	4604	18·2	4428	17·5	17·6
410			5155	20·0	4973	19·3	4791	18·7	4608	18·0	18·2
400			5361	20·6	5171	19·8	4982	19·1	4792	18·4	19·0
390			5572	21·1	5375	20·4	5178	19·6	4981	18·9	19·7
380			5788	21·6	5583	20·8	5379	20·1	5174	19·3	20·5
370			6010	22·2	5797	21·4	5585	20·6	5372	19·8	21·3
360			6238	22·8	6017	22·0	5797	21·2	5576	20·4	22·1
350			6473	23·5	6244	22·7	6015	21·8	5786	21·0	22·9
340			6714	24·1	6477	23·3	6239	22·4	6002	21·6	23·7
330			6963	24·9	6716	23·9	6470	23·1	6224	22·2	24·6
320			7219	25·6	6964	24·8	6709	23·9	6453	22·9	25·5
310			7483	26·4	7219	25·5	6954	24·5	6690	23·7	26·4
300			7757	27·4	7482	26·3	7208	25·4	6934	24·4	27·4
290			8039	28·2	7755	27·3	7471	26·3	7186	25·2	28·4
280			8331	29·2	8037	28·2	7742	27·1	7448	26·2	29·4
270			8634	30·3	8329	29·2	8024	28·2	7718	27·0	30·5
260			8949	31·5	8633	30·4	8317	29·3	8000	28·2	31·6
250			9276	32·7	8948	31·5	8620	30·3	8292	29·2	32·8
250			9276	37·2	8948	35·9	8620	34·6	8292	33·2	32·8
200			11153	48·0	10742	46·3	10348	44·6	9954	42·9	39·4
150			13536	67·8	13058	65·4	12579	63·0	12101	60·6	47·8
100			16925	115·8	16327	111·7	15729	107·6	15130	103·6	59·8
50			22717		21914		21110		20308		80·3

The small figures between each line give the alteration in height for a difference of pressure of 1 mm.

Example :—If the pressure at the lower station is 730 mm., at the upper station 480 mm., and the mean temperature of the air between the two stations is 10°, then the difference in height of the two stations is 3843 − 356 = 3487 metres.

TABLE XIV.

REDUCTION OF THE MERCURY BAROMETER TO 0° C.

	Barometric reading in millimetres.								
	400	450	500	550	600	650	700	750	800
Temp. 0° C.	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
2	0·1	0·2	0·2	0·2	0·2	0·2	0·2	0·3	0·3
4	0·3	0·3	0·3	0·4	0·4	0·4	0·5	0·5	0·5
6	0·4	0·4	0·5	0·5	0·6	0·6	0·7	0·7	0·8
8	0·5	0·6	0·6	0·7	0·8	0·8	0·9	1·0	1·0
10	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·2	1·3
12	0·7	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6
14	0·9	1·0	1·1	1·2	1·4	1·5	1·6	1·7	1·8
16	1·0	1·2	1·3	1·4	1·6	1·7	1·8	2·0	2·1
18	1·2	1·4	1·5	1·6	1·8	1·9	2·0	2·2	2·3
20	1·3	1·5	1·6	1·8	2·0	2·1	2·3	2·5	2·6
22	1·4	1·7	1·8	2·0	2·2	2·3	2·5	2·7	2·9
24	1·6	1·8	2·0	2·2	2·3	2·5	2·7	2·9	3·1
26	1·7	1·9	2·1	2·3	2·5	2·8	3·0	3·2	3·4
28	1·8	2·1	2·3	2·5	2·7	3·0	3·2	3·4	3·6
30	2·0	2·2	2·5	2·7	3·0	3·2	3·4	3·7	3·9
32	2·1	2·3	2·6	2·9	3·1	3·4	3·6	3·9	4·2
34	2·3	2·5	2·8	3·0	3·3	3·6	3·9	4·1	4·4
36	2·4	2·6	2·9	3·2	3·5	3·8	4·1	4·4	4·7
38	2·5	2·8	3·1	3·4	3·7	4·0	4·3	4·6	4·9
40	2·6	2·9	3·3	3·6	3·9	4·3	4·6	4·9	5·2

The numbers are to be $\left\{\begin{matrix}\text{subtracted}\\ \text{added}\end{matrix}\right\}$ for temperatures $\left\{\begin{matrix}\text{above}\\ \text{below}\end{matrix}\right\}$ 0° C.

FORMULAE (*cf.* CHAP. IV.)

(1) $$A = 1{\cdot}293\,(1 - s).$$

(2) $$G = \frac{V.A}{n}.$$

(3) $$n = \frac{V.A}{G}.$$

(4) $$r = \frac{3\,mn}{A}.$$

Renard's Law of the Three Cubes (5) $V = \dfrac{36\pi m^3 n^3}{A^3}$.

Height factor (6) $n = \dfrac{A}{m}\sqrt[3]{\dfrac{V}{36\pi}}$.

Normal height for hydrogen balloons:

(9) $$h_{0H} = -11833 + 6133 \log \frac{V}{m^3}.$$

Normal height for coal-gas balloons:

(10) $$h_{0G} = -15445 + 6133 \log \frac{V}{m^3}.$$

(11) $$n_0 = \frac{n}{\dfrac{g}{Om} + 1}.$$

Normal height for loaded balloons:

(12) $$h_0 = 18400 \log \frac{n}{\dfrac{g}{Om} + 1}.$$

Ballast formula:

(13) $$x = a\,.\,\frac{AV}{s}[(\bar{t}' - \underline{t}') - (\bar{t} - \underline{t})].$$

TABLE XV.

Calculation of the Normal Height of a Balloon.

$$h_0 = 18400 \log n.$$

If V is the volume of the balloon in cubic metres, A = the lift or buoyancy of a cubic metre of the gas in kg. at a barometric pressure = b mm. and at 0° C., G the weight of the loaded balloon in kg., then $n = \frac{VA}{G}$, and the table gives the normal height attainable by the balloon above the niveau where the barometric height $p = b$ mm.

n	0	1	2	3	4	5	6	7	8	9	10
1·0	...	79	158	236	313	390	466	541	615	689	762
1·1	762	834	906	977	1047	1117	1186	1255	1323	1390	1457
1·2	1457	1524	1590	1654	1718	1782	1846	1910	1973	2035	2097
1·3	2097	2158	2219	2280	2339	2397	2456	2515	2573	2631	2688
1·4	2688	2745	2802	2888	2913	2969	3025	3079	3134	3187	3240
1·5	3240	3294	3346	3398	3450	3502	3553	3604	3656	3706	3755
1·6	3755	3805	3854	3903	3952	4001	4049	4098	4146	4193	4239
1·7	4239	4286	4333	4379	4425	4471	4517	4563	4608	4653	4698
1·8	4698	4742	4786	4879	4872	4916	4959	5002	5045	5088	5130
1·9	5130	5172	5213	5255	5296	5337	5378	5419	5459	5499	5539

$n = 4$ corresponds to twice the height of $n = 2$
$n = 8$,, three times ,, $n = 2$
$n = 16$,, four ,, ,, $n = 2$
$n = 2^m$,, m ,, ,, $n = 2$

Example 1 : $n = 1·645$.

The h corresponding to $n = 1·64$ is 3952,
,, ,, $n = 1·65$,, 4001,

Difference = 49,

whence for $n = 1·645$, $h = 3952 + 49 \times 0·5 = 3977$ metres.

Example 2 : $n = 8·543$.

$$\log n = \log 8·543 = \log\left(8 \times \frac{8·543}{8}\right)$$

$$= \log 8 + \log 1·068.$$

whence $h = 18400 \log 8 + 18400 \log 1·068$.

For $n = 8 = 2^3$ the table gives $h = 3 \times 5539 = 16617$ m.
$n = 1·068$,, $h =$ 526 m.

whence for $n = 8·543$,, $h =$ 17143 m.

TABLE XVI.

Comparison of the Relations between Size and Lift (Buoyancy) for different Spherical Balloons.

Diameter of the Balloon.	Circumference of the Balloon.	Contents of the Balloon.	Surface of the Balloon.	Buoyancy of the Balloon filled with Hydrogen.	Buoyancy of the Balloon filled with Coal Gas.
$D=\sqrt[3]{\frac{6V}{\pi}}$	$=\pi D$	$V=\frac{4}{3}\pi r^3$	$=\pi D^2$ or $=4\pi r^2$	$A.V=1{\cdot}1V$	$A.V=0{\cdot}7V$
in metres.	in metres.	in cb. m.	in sq. m.	in kg.	in kg.
0·25	0·785	0·008	0·160	0·009	0·005
0·50	1·571	0·065	0·785	0·072	0·046
0·75	2·356	0·221	1·767	0·243	0·155
1·00	3·142	0·524	3·142	0·576	0·367
1·25	3·927	1·023	4·909	1·125	0·716
1·50	4·712	1·767	7·068	1·944	1·237
1·75	5·498	2·806	9·621	3·087	1·964
2·00	6·283	4·188	12·56	4·608	2·932
2·25	7·069	5·964	15·90	6·560	4·175
2·50	7·854	8·181	19·64	8·999	5·727
2·75	8·639	10·89	23·76	11·98	7·622
3·00	9·425	14·14	28·27	15·55	9·896
3·25	10·21	17·94	33·18	19·73	12·56
3·50	11·00	22·45	38·48	24·70	15·72
3·75	11·78	26·37	44·18	29·01	18·46
4·00	12·37	33·51	50·27	36·86	23·46
4·25	13·14	40·19	56·74	44·21	28·14
4·50	14·14	47·72	63·62	52·49	33·40
4·75	14·92	56·11	70·88	61·73	39·28
5·00	15·71	65·45	78·54	72·00	45·81
5·50	17·28	87·11	95·03	95·82	60·98
5·76	18·10	100	104	110	70·00
6·00	18·85	113	113	124	79·17
6·50	20·42	144	133	158	111
6·59	20·67	150	136	165	115
7·00	21·99	180	154	198	126
7·26	23·33	200	173	220	140

TABLE XVI.—*continued.*

Diameter of the Balloon.	Circumference of the Balloon.	Contents of the Balloon.	Surface of the Balloon.	Buoyancy of the Balloon filled with	
				Hydrogen.	Coal Gas.
$D = \sqrt[3]{\frac{6V}{\pi}}$	$= \pi D$	$V = \frac{4}{3}\pi r^3$	$= \pi D^2$ or $= 4\pi r^2$	$A.V = 1{\cdot}1\,V$	$A.V = 0{\cdot}7\,V$
in metres.	in metres.	in cb. m.	in sq. m.	in kg.	in kg.
7·50	23·56	221	177	243	155
7·82	24·50	250	191	275	175
8·00	25·13	268	201	295	188
8·30	26·07	300	216	330	210
8·50	26·70	322	227	354	225
8·74	27·46	350	240	385	245
9·00	28·27	382	254	420	267
9·14	29·38	400	275	440	280
9·50	29·85	450	284	495	325
9·85	30·91	500	304	550	350
10·00	31·42	524	314	576	366
10·47	32·86	600	344	660	420
10·50	32·99	606	346	661	424
11·00	34·56	697	380	767	487
11·02	34·62	700	382	770	490
11·50	36·12	796	416	875	557
11·52	36·19	800	417	880	560
11·98	37·64	900	451	990	630
12·00	37·70	905	452	995	633
12·41	38·96	1000	483	1100	700
12·50	39·27	1024	491	1126	716
13·00	40·84	1150	531	1265	805
13·18	41·41	1200	546	1320	840
13·50	42·41	1288	573	1417	901
13·88	43·60	1400	605	1540	980
14·00	43·98	1437	616	1580	1005
14·50	45·55	1596	660	1755	1117
14·51	45·56	1600	661	1760	1120
15·00	47·11	1767	707	1944	1236
15·09	47·37	1800	714	1980	1260
15·50	48·70	1950	755	2145	1365
15·63	49·07	2000	767	2200	1400

TABLE XVI.—*continued.*

Diameter of the Balloon.	Circumference of the Balloon.	Contents of the Balloon.	Surface of the Balloon.	Buoyancy of the Balloon filled with	
				Hydrogen.	Coal Gas.
$D=\sqrt[3]{\frac{6V}{\pi}}$	$=\pi D$	$V=\frac{4}{3}\pi r^3$	$=\pi D^2$ or $=4\pi r^2$	$A.V=1{\cdot}1V$	$A.V=0{\cdot}7V$
in metres.	in metres.	in cb. m.	in sq. m.	in kg.	in kg.
16·00	50·26	2145	804	2360	1501
16·50	51·84	2350	855	2585	1645
16·84	52·90	2500	891	2750	1750
17 00	53·41	2572	908	2829	1800
17·50	54·98	2810	982	3091	1967
17·89	56·17	3000	1004	3300	2100
18·00	56·55	3054	1018	3359	2137
18·50	58·12	3350	1075	3685	2345
18·84	59·19	3500	1115	3750	2450
19·00	59·69	3590	1134	3949	2513
19·50	61·26	3880	1195	4268	2716
19·69	61·82	4000	1217	4400	2800
20·00	62·83	4189	1257	4608	2932
20·48	64·34	4500	1318	4900	3150
20·50	64·40	4511	1320	4962	3157
21·00	65·97	4850	1385	5335	3235
21·22	66·67	5000	1415	5500	3500

TABLE XVII.—Strengths of Balloon Envelopes.

1. *Hydrogen Balloons.* (A = 1·1.)

Contents of the Balloon.	Diameter of the Balloon.	Maximum Internal Pressure.	Testing Pressure.	Maximum Tension per lin. meter.	Tearing stress of the material for strips 18 cm. long and 5 cm. broad.		Increase of Tension.		Increase in tearing stress of strips 18 cm. long and 5 cm. broad.			
							Per 1 kg. per sq. m. on the tail.	Per 1 metre length of the tail.	For each extra kg. pressure on the tail.		For each extra metre in length of the tail.	
V	D	$Q = A(D+l)$	$P = 2Q$	$T = \frac{A(D+l)D}{4}$	$k=6$ $R = \frac{6}{20}T$	$k=10$ $R = \frac{10}{20}T$	$\Delta T = \frac{D}{4}$	$\Delta T_A = \frac{A \cdot D}{4}$	$k=6$ $\delta R = \frac{6}{20}\Delta T$	$k=10$ $\delta R = \frac{10}{20}\Delta T$	$k=6$ $\delta R_A = \frac{6}{20}\Delta T_A$	$k=10$ $\delta R_A = \frac{10}{20}\Delta T_A$
cb. m.	metres	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.
100	5·759	6·815	14	9·812	3	5	1·440	1·584	0·432	0·720	0·475	0·792
250	7·816	9·359	19	18·287	5	9	1·954	2·149	0·586	0·977	0·645	1·075
500	9·847	11·905	24	29·308	9	15	2·462	2·708	0·739	1·231	0·812	1·354
600	10·465	12·686	25	33·190	10	17	2·616	2·878	0·785	1·308	0·863	1·439
700	11·016	13·389	27	36·873	11	18	2·754	3·029	0·826	1·377	0·909	1·515
800	11·518	14·029	28	40·397	12	20	2·880	3·167	0·864	1·440	0·950	1·584
900	11·979	14·620	29	43·784	13	22	2·995	3·294	0·898	1·497	0·988	1·647
1000	12·407	15·116	30	47·040	14	24	3·102	3·412	0·931	1·551	1·024	1·706
1200	13·184	16·166	32	53·283	16	27	3·296	3·626	0·989	1·646	1·088	1·813
1400	13·880	17·068	34	59·226	18	30	3·470	3·817	1·041	1·735	1·145	1·909
1600	14·511	17·885	36	64·883	19	32	3·628	3·991	1·088	1·814	1·197	1·996
1800	15·092	18·638	37	70·321	21	35	3·773	4·150	1·132	1·887	1·245	2·075
2000	15·632	19·342	39	75·589	23	38	3·908	4·299	1·172	1·954	1·290	2·150
2500	16·839	20·925	42	88·090	26	44	4·210	4·631	1·263	2·105	1·389	2·316
3000	17·894	22·315	45	99·826	30	50	4·474	4·921	1·341	2·237	1·476	2·461
3500	18·838	23·564	47	110·975	33	55	4·710	5·180	1·413	2·355	1·555	2·590
4000	19·695	24·701	49	121·623	36	61	4·924	5·416	1·477	2·462	1·625	2·708
4500	20·484	25·753	52	131·881	40	66	5·121	5·663	1·536	2·561	1·690	2·817
5000	21·216	26·734	53	141·797	43	71	5·304	5·834	1·591	2·652	1·750	2·917

TABLE XVII.—STRENGTH OF BALLOON ENVELOPES.

2. *Coal-gas Balloons.* (A = 0·7.)

Contents of the Balloon.	Diameter of the Balloon.	Maximum Internal Pressure.	Testing Pressure.	Maximum Tension per lineal metre.	Tearing stress of the material for strips 18 cm. long and 5 cm. broad.		Increase of Tension.		Increase in tearing stress of strips 18 cms. long and 5 cms. broad.			
							Per 1 kg. per sq.m. on the tail.	Per 1 metre length of the tail.	For each extra kg. pressure on the tail.		For each extra metre of length of tail.	
V	D	$Q = A(D+l)$	$P = 2Q$	$T = \frac{A(D+l)D}{4}$	$k=6$ $R = \frac{6}{20}T$	$k=10$ $R = \frac{10}{20}T$	$\Delta T = \frac{D}{4}$	$\Delta T_A = \frac{A.D}{4}$	$k=6$ $\delta R = \frac{6}{20}\Delta T$	$k=10$ $\delta R = \frac{10}{20}\Delta T$	$k=6$ $\delta R_A = \frac{6}{20}\Delta T_A$	$k=10$ $\delta R_A = \frac{10}{20}\Delta T_A$
cb.m.	metres.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.
100	5·759	4·415	9	6·356	2	3	1·440	1·001	0·432	0·720	0·300	0·501
250	7·816	6·076	12	11·873	4	6	1·954	1·368	0·586	0·977	0·410	0·684
500	9·847	7·753	16	19·086	6	10	2·462	1·723	0·739	1·231	0·517	0·862
600	10·465	8·264	17	21·621	6	11	2·616	1·831	0·785	1·308	0·549	0·916
700	11·016	8·725	17	24·029	7	12	2·754	1·928	0·826	1·377	0·578	0·964
800	11·518	9·146	18	26·336	8	13	2·880	2·016	0·864	1·440	0·605	1·008
900	11·979	9·533	19	28·549	9	14	2·995	2·096	0·898	1·497	0·629	1·048
1000	12·407	9·897	20	30·695	9	15	3·102	2·171	0·931	1·551	0·651	1·086
1200	13·184	10·557	21	34·796	10	17	3·296	2·307	0·989	1·646	0·692	1·154
1400	13·880	11·150	22	38·691	12	19	3·470	2·429	1·041	1·735	0·729	1·215
1600	14·511	11·689	23	42·405	13	21	3·628	2·539	1·088	1·814	0·762	1·270
1800	15·092	12·188	24	45·985	14	23	3·773	2·642	1·132	1·887	0·793	1·321
2000	15·632	12·656	25	49·460	15	25	3·908	2·736	1·172	1·954	0·821	1·368
2500	16·839	13·703	27	57·676	17	29	4·209	2·946	1·263	2·105	0·884	1·474
3000	17·894	14·623	29	65 416	20	33	4·474	3·131	1·342	2·237	0·939	1·566
3500	18·838	15·452	31	72·771	22	36	4·710	3·297	1·413	2·355	0·989	1·649
4000	19·695	16·209	32	79·810	24	40	4·924	3·447	1·477	2·462	1·034	1·724
4500	20·484	16·909	34	86·591	26	43	5·121	3·585	1·536	2·561	1·076	1·793
5000	21·216	17·955	35	93·133	28	47	5·304	3·713	1·591	2·652	1·114	1·857

TABLE XVIII.

CONVERSION OF WIND VELOCITIES FROM KILOMETRES PER HOUR INTO METRES PER SECOND.

Km. per hour.	0	1	2	3	4	5	6	7	8	9
	Metres per second.									
0	0·0	0·3	0·6	0·8	1·1	1·4	1·7	1·9	2·2	2·5
10	2·8	3·1	3·3	3·6	3·9	4·2	4·4	4·7	5·0	5·3
20	5·6	5·8	6·1	6·4	6·7	6·9	7·2	7·5	7·8	8·1
30	8·3	8·6	8·9	9·2	9·4	9·7	10·0	10·3	10·6	10·8
40	11·1	11·4	11·7	11·9	12·2	12·5	12·8	13·1	13·3	13·6
50	13·9	14·2	14·4	14·7	15·0	15·3	15·6	15·8	16·1	16·4
60	16·7	16·9	17·2	17·5	17·8	18·1	18·3	18·6	18·9	19·2
70	19·4	19·7	20·0	20·3	20·6	20·8	21·1	21·4	21·7	21·9
80	22·2	22·5	22·7	23·1	23·3	23·6	23·9	24·2	24·4	24·7
90	25·0	25·3	25·6	25·8	26·1	26·4	26·7	26·9	27·2	27·5

TABLE XIX.

Difference in Times between various Towns and Greenwich.

Name of Town.	Mean local time at Greenwich noon.	Greenwich time at noon (local time).
Aix-la-Chapelle,	12.24 p.m.	11.36 a.m.
Amsterdam,	12.20 ,,	11.40 ,,
Antwerp,	12.18 ,,	11.42 ,,
Astrachan,	3.12 ,,	8.48 ,,
Athens,	1.35 ,,	10.25 ,,
Basle,	12.30 ,,	11.30 ,,
Batavia,	7.7 ,,	4.53 ,,
Berlin,	12.54 ,,	11.6 ,,
Berne,	12.30 ,,	11.30 ,,
Bologna,	12.45 ,,	11.15 ,,
Bonn,	12.32 ,,	11.28 ,,
Bregence,	12.39 ,,	11.21 ,,
Breslau,	1.8 ,,	10.52 ,,
Brest,	11.42 a.m.	12.18 p.m.
Brünn,	1.6 p.m.	10.54 a.m.
Brussels,	12.17½ ,,	11.42½ ,,
Buenos Ayres,	8.6 a.m.	3.54 p.m.
Cairo,	2.5 p.m.	9.55 a.m.
Calcutta,	5.54 ,,	6.6 ,,
Cambridge,	noon.	noon.
Canton,	7.33 p.m.	4.27 a.m.
Chicago,	6.10 a.m.	5.50 p.m.
Christiana,	12.43 p.m.	11.17 a.m.
Cincinnati,	6.22 a.m.	5.38 p.m.
Cologne,	12.28 p.m.	11.32 a.m.
Constantinople,	1.56 ,,	10.4 ,,
Copenhagen,	12.50 ,,	11.10 ,,
Dorpat,	1.47 ,,	10.13 ,,
Dresden,	12.55 ,,	11.5 ,,
Dublin,	11.35 a.m.	12.25 p.m.
Edinburgh,	11.47 ,,	12.13 ,,
Ferro,	10.49 ,,	1.11 ,,
Florence,	12.45 p.m.	11.15 a.m.

TABLE XIX.—*continued.*

Name of Town.	Mean local time at Greenwich noon.	Greenwich time at noon (local time).
Frankfort-on-Main, ...	12.35 p.m.	11.25 a.m.
San Francisco, ...	3.50 a.m.	8.10 p.m.
Geneva, ...	12.25 p.m.	11.35 a.m.
Göttingen, ...	12.40 ,,	11.20 ,,
Graz, ...	1.2 ,,	10.58 ,,
Greenwich, ...	noon.	noon.
Hamburg, ...	12.40 p.m.	11.20 a.m.
Heidelburg, ...	12.35 ,,	11.25 ,,
Helsingfors, ...	1.40 ,,	10.20 ,,
Ispahan, ...	3.27 ,,	8 33 ,,
Jerusalem, ...	2.21 ,,	9.39 ,,
Kiev, ...	2.2 ,,	9.58 ,,
La Hague, ...	12.17 ,,	11.43 ,,
Laibach, ...	12.58 ,,	11.2 ,,
Leiden, ...	12.18 ,,	11.42 ,,
Leipsic, ...	12.50 ,,	11.10 ,,
Lima, ...	6.51½ a.m.	5.8½ p.m.
Linz, ...	12.57 p.m.	11.3 a.m.
Lisbon, ...	11.23 a.m.	12.37 p.m.
Liverpool, ...	11.48 ,,	12.12 ,,
London, ...	noon.	noon.
Lund, ...	12.53 p.m.	11.7 a.m.
Madras, ...	5.21 ,,	6.39 ,,
Madrid, ...	11.45 a.m.	12.15 p.m.
Milan, ...	12.37 p.m.	11.23 a.m.
Marseilles, ...	12.21½ ,,	11.38½ ,,
Melbourne, ...	9.40 ,,	2.20 ,,
Mexico, ...	5.24 a.m.	6.36 p.m.
Modene, ...	12.44 p.m.	11.16 a.m.
Moscow, ...	2.30 ,,	9.30 ,,
Munich, ...	12.46 ,,	11.14 ,,
Naples, ...	12.57 ,,	11.3 ,,
New Orleans, ...	5.59½ a.m.	6.0½ p.m.
New York, ...	7.4 ,,	4.56 ,,
Olmütz, ...	1.9 p.m.	10.51 a.m.
Oxford, ...	11.55 a.m.	12.5 p.m.

TABLE XIX.—*continued.*

Name of Town.	Mean local time at Greenwich noon.	Greenwich time at noon (local time).
Padua,	12.47½ p.m.	11.12½ a.m.
Palermo,	12.53 ,,	11.7 ,,
Paris,	12.9 ,,	11.51 ,,
Pekin,	7.46 ,,	4.14 ,,
Philadelphia,	6.59 a.m.	5.1 p.m.
Prague,	12.58 p.m.	11.2 a.m.
Pulkova,	2.1 ,,	9.59 ,,
Riga,	1.37 ,,	10.23 ,,
Rio de Janeiro,	9.7 a.m.	2.53 p.m.
Rome,	2.50 p.m.	11.10 a.m.
Rotterdam,	12.18 ,,	11.42 ,,
Sevastapol,	2 14 ,,	9.46 ,,
St Helena,	11.37 a.m.	12.23 p.m.
St Petersburg,	2.1 p.m.	9.59 a.m.
Stockholm,	11.12 ,,	10.48 ,,
Strassburg,	12.31 ,,	11.29 ,,
Sydney,	10.5 ,,	1.55 ,,
Teneriffe,	10.53 a.m.	1.7 p.m.
Tiflis,	2.59 p.m.	9.1 a.m.
Trieste,	12.55 ,,	11.5 ,,
Turin,	12.31 ,,	11.29 ,,
Upsala,	1.10½ ,,	10.49½ ,,
Valparaiso,	7.14 a.m.	4.46 p.m.
Venice,	12.49 p.m.	11.11 a.m.
Vienna,	1.5½ ,,	10.54½ ,,
Warsaw,	1.24 ,,	10.36 ,,
Washington,	6.52 a.m.	5.8 p.m.
Zurich,	12.34 p.m.	11.26 a.m.

TABLE XX.

Times of Sunrise and Sunset according to the Mean Time of the Place.

Latitude.		Sunrise.					Sunset.				
		48°	50°	52°	54°	56°	48°	50°	52°	54°	56°
		h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Jan.	1	7 52	8 1	8 11	8 22	8 35	4 15	4 6	3 56	3 45	3 32
,,	11	7 50	7 58	8 7	8 17	8 29	4 26	4 18	4 9	3 59	3 47
,,	21	7 43	7 50	7 59	8 7	8 17	4 40	4 33	4 25	4 16	4 6
Feb.	1	7 31	7 37	7 44	7 51	7 59	4 57	4 51	4 45	4 37	4 29
,,	11	7 16	7 21	7 26	7 32	7 38	5 13	5 8	5 3	4 58	4 52
,,	21	6 59	7 3	7 7	7 11	7 15	5 29	5 26	5 22	5 18	5 14
Mar.	1	6 45	6 47	6 50	6 53	6 56	5 42	5 39	5 37	5 34	5 31
,,	11	6 25	6 26	6 27	6 28	6 29	5 57	5 56	5 54	5 53	5 52
,,	21	6 4	6 4	6 4	6 4	6 4	6 11	6 11	6 12	6 12	6 12
Apr.	1	5 42	5 40	5 39	5 37	5 34	6 27	6 29	6 31	6 33	6 36
,,	11	5 22	5 19	5 16	5 12	5 8	6 41	6 44	6 48	6 51	6 55
,,	21	5 3	4 59	4 54	4 49	4 43	6 56	7 0	7 5	7 10	7 16
May	1	4 45	4 40	4 34	4 27	4 20	7 10	7 15	7 22	7 28	7 35
,,	11	4 30	4 23	4 16	4 7	3 58	7 24	7 30	7 38	7 46	7 55
,,	21	4 17	4 9	4 1	3 51	3 40	7 36	7 44	7 53	8 2	8 13
June	1	4 7	3 58	3 49	3 38	3 26	7 48	7 57	8 7	8 18	8 30
,,	11	4 2	3 53	3 43	3 31	3 19	7 57	8 6	8 16	8 28	8 40
,,	21	4 2	3 52	3 41	3 29	3 16	8 1	8 10	8 21	8 33	8 46
July	1	4 6	3 56	3 46	3 34	3 22	8 1	8 10	8 21	8 33	8 45
,,	11	4 13	4 4	3 54	3 43	3 31	7 57	8 6	8 15	8 27	8 39
,,	21	4 23	4 15	4 6	3 56	3 46	7 48	7 56	8 5	8 15	8 25
Aug.	1	4 36	4 30	4 22	4 14	4 5	7 35	7 42	7 49	7 57	8 6
,,	11	4 49	4 44	4 38	4 31	4 24	7 20	7 25	7 31	7 38	7 45
,,	21	5 3	4 59	4 54	4 49	4 43	7 2	7 6	7 11	7 16	7 22

TABLE XX.—*continued.*

Latitude.	Sunrise. 48°	50°	52°	54°	56°	Sunset. 48°	50°	52°	54°	56°
	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
Sept. 1	5 18	5 15	5 12	5 8	5 4	6 41	6 44	6 47	6 51	6 55
,, 11	5 32	5 30	5 28	5 26	5 24	6 21	6 23	6 24	6 26	6 28
,, 21	5 45	5 45	5 45	5 44	5 44	6 0	6 0	6 1	6 1	6 1
Oct. 1	5 59	6 0	6 1	6 2	6 3	5 39	5 38	5 38	5 36	5 35
,, 11	6 14	6 16	6 18	6 20	6 23	5 19	5 17	5 15	5 12	5 9
,, 21	6 29	6 32	6 36	6 40	6 45	5 0	4 57	4 53	4 49	4 44
Nov. 1	6 45	6 50	6 56	7 1	7 8	4 41	4 36	4 31	4 25	4 18
,, 11	7 1	7 7	7 14	7 21	7 30	4 27	4 21	4 14	4 6	3 57
,, 21	7 16	7 23	7 31	7 40	7 50	4 15	4 8	4 0	3 51	3 41
Dec. 1	7 30	7 38	7 47	7 57	8 9	4 8	4 0	3 51	3 40	3 28
,, 11	7 41	7 50	8 0	8 11	8 24	4 5	3 56	3 46	3 35	3 22
,, 21	7 49	7 58	8 8	8 19	8 31	4 7	3 58	3 48	3 36	3 22

TABLE XXI.

Legendre's Elliptical Functions.

Θ	K	E_1	F_1	Θ	K	E_1	F_1
0°	0·0000	1·5708	1·5708				
1	0·0175	1·5707	1·5709	11°	0·1908	1·5564	1·5854
2	0·0349	1·5703	1·5713	12	0·2079	1·5537	1·5882
3	0·0523	1·5697	1·5719	13	0·2250	1·5507	1·5913
4	0·0698	1·5689	1·5727	14	0·2419	1·5476	1·5946
5	0·0872	1·5678	1·5738	15	0·2588	1·5442	1·5981
6	0·1045	1·5665	1·5751	16	0·2756	1·5405	1·6020
7	0·1219	1·5649	1·5767	17	0·2924	1·5367	1·6061
8	0·1392	1·5632	1·5785	18	0·3090	1·5326	1·6105
9	0·1564	1·5611	1·5805	19	0·3256	1·5283	1·6151
10	0·1736	1·5589	1·5828	20	0·3420	1·5238	1·6200

TABLE XXI.—*continued.*

Θ	K	E_1	F_1	Θ	K	E_1	F_1
21°	0·3584	1·5191	1·6252	56°	0·8290	1·2492	2·0571
22	0·3746	1·5141	1·6307	57	0·8387	1·2397	2·0804
23	0·3907	1·5090	1·6365	58	0·8480	1·2301	2·1047
24	0·4067	1·5037	1·6426	59	0·8572	1·2206	2·1300
25	0·4226	1·4981	1·6490	60	0·8660	1·2111	2·1565
26	0·4384	1·4924	1·6557	61	0·8746	1·2015	2·1842
27	0·4540	1·4864	1·6627	62	0·8829	1·1920	2·2132
28	0·4695	1·4803	1·6701	63	0·8910	1·1826	2·2435
29	0·4848	1·4740	1·6777	64	0·8988	1·1732	2·2754
30	0·5000	1·4675	1·6858	65	0·9063	1·1638	2·3088
31	0·5150	1·4608	1·6941	66	0·9135	1·1545	2·3439
32	0·5299	1·4539	1·7028	67	0·9205	1·1453	2·3809
33	0·5446	1·4467	1·7119	68	0·9272	1·1362	2·4198
34	0·5592	1·4397	1·7214	69	0·9336	1·1272	2·4610
35	0·5736	1·4323	1·7312	70	0·9397	1·1184	2·5046
36	0·5878	1·4248	1·7415	71	0·9455	1·1096	2·5507
37	0·6018	1·4171	1·7522	72	0·9511	1·1011	2·5998
38	0·6157	1·4092	1·7633	73	0·9563	1·0927	2·6521
39	0·6293	1·4013	1·7748	74	0·9613	1·0844	2·7081
40	0·6428	1·3931	1·7868	75	0·9659	1·0764	2·7681
41	0·6561	1·3849	1·7992	76	0·9703	1·0686	2·8327
42	0·6691	1·3765	1·8122	77	0·9744	1·0611	2·9026
43	0·6820	1·3680	1·8256	78	0·9781	1·0538	2·9786
44	0·6947	1·3594	1·8396	79	0·9816	1·0468	3·0617
45	0·7071	1·3506	1·8541	80	0·9848	1·0401	3·1534
46	0·7193	1·3418	1·8691	81	0·9877	1·0338	3·2553
47	0·7314	1·3329	1·8848	82	0·9903	1·0278	3·3699
48	0·7431	1·3238	1·9011	83	0·9925	1·0223	3·5004
49	0·7547	1·3147	1·9180	84	0·9945	1·0172	3·6519
50	0·7660	1·3055	1·9356	85	0·9962	1·0127	3·8317
51	0·7771	1·2963	1·9539	86	0·9976	1·0086	4·0528
52	0·7880	1·2870	1·9729	87	0·9986	1·0053	4·3387
53	0·7986	1·2776	1·9927	88	0·9994	1·0026	4·7427
54	0·8090	1·2681	2·0133	89	0·9998	1·0008	5·4349
55	0·8192	1·2587	2·0847	90	1·0000	1·0000	∞

TABLE XXII.

DATA RELATING TO CERTAIN MODERN AIR-SHIPS.

Type.	Volume in cb. m.	Length, L, in m.	Diameter, D, in m.	Master Section, S, in sq. m.	Make of Motor.	Nominal H.P.	Effective H.P.	Weight, P, including Fuel for 10 hours, in kg.	Total Lift, A, in kg.	Net Lift = A − P kg.	Ratio D : L.	Ratio H.P./S in H.P. per sq. m.	Benzine per H.P.-hour in kg.	Independent Velocity in m. per sec.	Coefficient ζ.	Total Weight in kg. per m. in length.	Total Weight in kg. per cb. m. contents.	Maximum Velocity attained in m. per sec.	Probable Maximum Duration of Ascent in hours.	Probable Circle of Action, radius in km.
v. Parseval, 1906.	2500	48	8·57	62	Mercedes-Daimler.	90	67·5	1900	2750	850	5·6	1·46	..	10	0·08165	39·6	0·760	..	..	..
Lebaudy I., 1905.	2950	58	10·30	85	,,	50	37·5	2260	3300	1040	5·9	0·6	0·36	11	0·02486	39	0·766	11·8	16	340
Lebaudy II., "La Patrie," 1906.	3150	60	10·30	85	Panhard Vavasseur.	70	52	..	3530	..	5·8	0·8	0·36	..	..	..	..	..	..	..
Graf. v. Zeppelin, Model III., 1906.	11431	128	11·70	110	Mercedes-Daimler (2 motors).	170	130	9470	12575	3105	10·9	1·55	0·23	13·5	0·03602	74	0·828	15	60	1500

PHOTOGRAPHIC FORMULÆ.

Developers.

1. *Iron oxalate* developer.

Solution I.	Potassium oxalate,	200 gm.
	Water,	800 c.c.
Solution II.	Ferrous sulphate,	100 gm.
	Sulphuric acid,	5 drops.
	Water,	300 c.c.
Solution III.	Potassium bromide,	10 gm.
	Water,	100 c.c.

Use 30 c.c. of solution I. to 10 c.c. of solution II., and about 10 drops of solution III.

For over-exposed plate, use less of solution II. and more of solution III.

For under-exposed plates, immerse, previous to developing, in a solution of 1 gm. of sodium hyposulphate (hypo) in 1000 c.c. of water.

2. *Pyrogallic* acid developer.

Solution I.	Sodium sulphite (crystalline),	100 gm.
	Pyrogallic acid,	14 ,,
	Sulphuric acid,	8 drops.
	Water,	500 c.c.
Solution II.	Sodium carbonate (crystalline),	50 gm.
	Water,	1000 c.c.
Solution III.	Potassium citrate, or common salt,	10 gm.
	Water,	100 c.c.

Use 10 c.c. of solution I. to 20 c.c. of solution II., and two or three drops of solution III.

3. *Hydroquinone* developer.

Solution I.	Sodium sulphite,	40 gm.
	Hydroquinone,	6 ,,
	Water,	600 c.c.
Solution II.	Potassium carbonate,	50 gm.
	Water,	600 c.c.

Use equal quantities of each solution (say 20 c.c.).

To retard the development, add a few drops of a 10 per cent. potassium bromide solution.

4. *Eikonogen* developer.

Solution I.	Sodium sulphite, . . .	100 gm.
	Eikonogen, ...	25 ,,
	Sulphuric acid, . . .	8 drops.
	Water, ...	1500 c.c.
Solution II.	Sodium carbonate, . .	150 gm.
	Water, ...	1000 c.c.

Use 30 c.c. of solution I. to 10 c.c. of solution II., adding a few drops of bromide solution.

5. *Paramidophenol* (*Rodinol*) developer (a single solution developer).

Sodium sulphite, ...	80 gm.
Sodium carbonate, ...	80 ,,
Rodinol, ...	4 ,,
Water, ...	1000 c.c.

6. *Metol* developer.

Solution I.	Sodium sulphite, . . .	100 gm.
	Metol, ...	10 ,,
	Water, ...	1000 c.c.
Solution II.	Potassium carbonate, . .	100 gm.
	Water, ...	1000 c.c.

Use three parts of solution I. to one part of II.

7. *Amidol* developer.

Sodium sulphite, ...	50 gm.
Amidol, ...	5 ,,
Water, ...	1000 c.c.

Fixing Bath.

A 20 per cent. solution of hypo.

Reducer.

Solution I.	Hypo, ...	100 gm.
	Water, ...	500 c.c.

Solution II.	Potassium ferricyanide (red prussiate of potash), .	10 gm.
	Water, ...	50 c.c.

Use twenty parts of solution I. to one part of II.
(Not applicable to plates developed with iron oxalate.)

Intensifier.

Solution I.	Mercuric chloride, . .	2 gm.
	Water, ...	100 c.c.
Solution II.	Sodium sulphite, . . .	10 gm.
	Water, ...	80 c.c.

Immerse the negative in solution I. until it becomes greyish-white ; rinse, and immerse in solution II. till black, then wash and dry.

POSTAL INFORMATION.

INLAND POST.

Letter Post.

The prepaid rate of postage is as follows:—Not exceeding 4 oz. in weight, 1d. ; for every additional 2 oz., ½d. No letter may exceed 2 ft. in length, 1 ft. in width, or 1 ft. in depth. A letter posted unpaid is chargeable on delivery with double postage ; a letter insufficiently paid, with double the deficiency.

Post Cards.

The prepaid rate of postage is ½d., or on a reply post card, 1d. A post card posted unpaid is chargeable on delivery with a postage of 1d. Maximum size, 5½ in. × 3½ in. ; minimum size, 3¼ in. × 2¼ in.

Halfpenny Packet Post.

The halfpenny packet post can be used only for packets not exceeding 2 oz. in weight. Printed or written matter not in the nature of a letter, and printed or written on paper or some substance ordinarily used for printing or writing, may be transmitted by halfpenny packet post.

Parcel Post.

The rates of postage on parcels are as follows:—For a parcel not exceeding 1 lb. in weight, 3d. ; exceeding 1 lb. and not exceeding 2 lb., 4d. ; exceeding 2 lb. and not exceeding 3 lb.,

5d.; exceeding 3 lb. and not exceeding 5 lb., 6d.; exceeding 5 lb. and not exceeding 7 lb., 7d.; exceeding 7 lb. and not exceeding 8 lb., 8d.; exceeding 8 lb. and not exceeding 9 lb., 9d.; exceeding 9 lb. and not exceeding 10 lb., 10d.; exceeding 10 lb. and not exceeding 11 lb., 11d. No parcel may exceed 11 lb. in weight. Size :—The size allowed for an inland parcel is—greatest length, 3 ft. 6 in.; greatest length and girth combined, 6 ft.

Registration.

Correspondence of any kind (including parcels) can be registered. The ordinary registration fee is 2d. in addition to the postage. The limit of compensation payable for this fee is £5. By paying an increased registration fee an increased limit of compensation may be ensured; for particulars see the *Post Office Guide.*

Inland Telegrams.

The charge is 6d. for the first twelve words, including the address, and ½d. for every additional word.

FOREIGN AND COLONIAL POST.

Letter Post.

The prepaid rate of postage on letters from the United Kingdom for all Foreign Countries (except Egypt) is 2½d. per ½ oz.; from the United Kingdom to nearly all British possessions and to Egypt the letter rate is 1d. per ½ oz.

Post Cards.

The prepaid rate of postage on every post card for a destination outside the United Kingdom is 1d., and on every reply post card 2d.

Printed Papers and Commercial Papers.

The prepaid rate of postage on printed papers for all places abroad is ½d. per 2 oz., and on commercial papers is 2½d. for the first 10 oz., and ½d. per 2 oz. thereafter. The term "printed papers" includes newspapers, books, periodical works, pamphlets, sheets of music, visiting and address cards, proofs of printing, plans, maps, catalogues, prospectuses, announcements, circulars, notices, engravings, photographs, and designs. "Commercial papers" include legal documents, bills of lading, invoices, and other documents of a mercantile character, the manuscript of books and other literary works. Limit of size, 1 ft. 6 in. × 1 ft. × 1 ft. Limit of weight, 4 lb.

Samples.

The prepaid rate of postage on sample packets for all places abroad is 1d. for the first 4 oz., and ½d. per 2 oz. thereafter. The use of the sample post is restricted to (*a*) bona-fide trade samples of merchandise without saleable value, and (*b*) natural history specimens, geological specimens, and scientific specimens generally when sent for no commercial purpose.

Parcel Post.

For particulars consult the *Post Office Guide.*

Registration.

The fee chargeable for registration to places abroad is 2d. This secures an indemnity for loss of 50 francs in nearly all countries. Insurances may be effected on letters and parcels for abroad on payment of certain extra fees (maximum 2s. 3½d. for a limit of compensation of £120).

FOREIGN AND COLONIAL TELEGRAMS.

European System.

(Minimum Charge, 10d.)

	s.	d.	
Algeria,	0	2½	per word.
Austria and Hungary,	0	3	,,
Belgium,	0	2	,,
Bulgaria,	0	4	,,
Canary Islands and Azore,	0	9	,,
Denmark,	0	3	,,
France,	0	2	,,
Germany,	0	2	,,
Gibraltar,	0	3	,,
Greece and Greek Islands,	0	6	,,
Holland,	0	2	,,
Italy,	0	3	,,
Luxemburg,	0	2½	,,
Malta,	0	4½	,,
Morocco—Tangier,	0	4½	,,
,, Spanish Possessions,	0	3	,,
Norway,	0	3	,,
Portugal,	0	3	,,
Roumania,	0	3½	,,
Russia,	0	4½	,,
Servia,	0	3½	,,

	s.	d.	
Spain, ...	0	3	per word.
Sweden, ...	0	3½	,,
Switzerland, ...	0	3	,,
Turkey, ...	0	6½	,,

Extra-European Service.

	s.	d.	
Argentine Republic, ...	4	2	per word.
Australia, ...	3	0	,,
Bermuda, ...	2	6	,,
Bolivia, Chili, Colombia, Ecuador and Peru, ...	5	9	,,
Brazil, ... 3s. to	6	5	,,
British Central Africa, . . .	2	11	,,
Canada (Ontario and Quebec), .	1	0	,,
,, (Western), . . . up to	3	2	,,
Cape Colony, ...	2	6	,,
Ceylon, ...	2	1	,,
China, ...	4	5	,,
East Africa, ... 2s. 1d. to	3	7	,,
Egypt, ...	1	0	,,
British Guiana, ...	7	0	,,
India, ...	2	0	,,
Japan, ...	4	10	,,
Madeira, ...	1	0	,,
Malay Peninsula, ...	3	6	,,
Natal, ...	2	6	,,
New Zealand, ...	3	0	,,
Persia, ...	1	6	,,
Transvaal, ...	2	6	,,
United States, ... 1s. to	1	6	,,
West Africa, ... 3s. 6d. to	11	0	,,
West Indies, ... 1s. 8d. to	7	5	,,

MONEY ORDERS AND POSTAL ORDERS.

Inland Money Orders.

The rates of poundage on ordinary inland money orders are:—

For sums not exceeding £1,	.	2d.
,, above £1 but not exceeding £3,	.	3d.
,, ,, 3 ,, 10,	.	4d.
,, ,, 10 ,, 20,	.	6d.
,, ,, 20 ,, 30,	.	8d.
,, ,, 30 ,, 40,	.	10d.

Foreign and Colonial Money Orders.

	s.	d.
For sums not exceeding £1, ...	0	3
,, above £1 but not above £2, . .	0	6
,, ,, 2 ,, 4, . .	0	9
,, ,, 4 ,, 6, . .	1	0
,, ,, 6 ,, 8, . .	1	3
And 3d. for every additional £2 up to £38.		
And for £40, ...	5	3

Postal Orders.

Issued for 6d., 1s., 1s. 6d., 2s. and 2s. 6d. for a poundage of ½d.; for 3s. and multiples of 6d. thereafter up to 15s. for a poundage of 1d.; and for 15s. 6d. and multiples of 6d. thereafter up to 20s., and for 21s., for a poundage of 1½d.

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